WOODS HOLE OCEANOGRAPHIC INSTITUTION

REFERENCE NO. 66-11

OCEANOGRAPHIC AND UNDERWATER
ACOUSTICS RESEARCH

conducted during the period
1 May - 31 October 1965

WOODS HOLE, MASSACHUSETTS

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Woods Hole, Massachusetts

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April 1966

PROGRESS REPORT

Submitted to Undersea Warfare Branch Office of Naval Research under Contract Nonr-4029(00) NR 260-101.

Approved for Distribution Richard H. Backus
Richard H. Backus, Deputy Chairman
Department of Geophysics

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ABSTRACT

This progress report contains findings in 1) physical oceanography, 2) marine biology, 3) geology and geophysics, and 4) hydroacoustics. 1) Long-period internal waves are deduced from sound-velocity data between Bermuda and the Antilles. The region of the thermal front (usually found near 30°N) was thought on one occasion to be a generator of internal waves. 2) Midwater fishes were four times more abundant north of the front than south and midwater reverberation levels varied similarly. 3) Evidence obtained southeast of Charleston, S.C. shows that the continental shelf has been building out over the Blake Plateau. The gravity characteristics of many major rifts of the world reveal that as the width of the rift increases, the Bouguer anomalies become increasingly positive. 4) Observations support the hypothesis that diffraction effects are required to explain the sound propagation in convergence zones in the Mediterranean.

A major engineering accomplishment was the installation and use of Sea Spider on the Blake Plateau. Sea Spider is a near motionless platform for scientific measurements in the deep ocean. The development of an automatic digital depth-reading system for use with echo sounders on ships were successfully completed, improvements in seismic profiling techniques were made, and special coherency studies of towed hydrophone array noise have progressed.

INTRODUCTION AND SUMMARY

This report is an account of research activities under Contract Nonr-4029 with the Office of Naval Research for the period 1 May 1965 to 31 October 1965. The work was carried out mainly within the Department of Geophysics. During this report period, three cruises of the R/V CHAIN were mounted. On one of these cruises CHAIN was accompanied by GOSNOLD to the Blake Plateau to assist in the installation of the near-motionless subsurface buoy structure developed under Project SEA SPIDER. An evaluation of this successful effort strongly encourages planning of a deep ocean installation in the future. The new possibilities for research in oceanography, underwater acoustics, and submarine seismology that have been opened up by this engineering achievement have excited serious interest in further SEA SPIDER work from organizations outside of this Institution. A detailed evaluation of Project SEA SPIDER is underway. A partial engineering evaluation of the work is presented under PROJECT SEA SPIDER in the General Instrument Section and in the section on cruises. Related work performed during the Sea Spider cruise of CHAIN will be described in several sections in this progress report.

A second cruise of CHAIN to the region of the Blake Plateau was mounted for a geophysical investigation of a particularly interesting finding made during the SEA SPIDER cruise relating to the geological formation of the Blake Plateau and the continental shelf. Irregularities showed up in a subbottom seismic reflection horizon over the shelf, similar to the irregular scoured channels previously observed on the Blake Plateau and believed to be produced by the Gulf Stream. This subbottom horizon was shown to be an extension of the Blake Plateau beneath the sedimentary material of the continental shelf. This evidence suggests that the sedimentary material accumulating on the continental shelf has been gradually moving outward over the Blake Plateau accompanied by a slow eastward shift in the course of the Gulf Stream. A comprehensive examination of the geology of the Blake Plateau within the Department of Geology and Chemistry under K. O. Emery employing seismic reflection techniques contains further extension of the above observations.

A third cruise of CHAIN was mounted to the deep water of the Hatteras Abyssal Plain to compare the measurements of vertical reflection levels at 12 kc with measurements of vertical and oblique-reflection, broad-band signals taken at the same time. Summary accounts of the cruises are presented in the cruise section of this report.

Several interesting observations were made when the Sea Spider was installed. Numerous sound-velocimeter profiles, obtained while on station at the Sea Spider installation, revealed a marked three-layer structure undergoing substantial fluctuations. These observations are reported in the Physical Oceanography section. In addition, some oblique seismic-reflection measurements were obtained using the Sparker and the hydrophones incorporated in Sea Spider legs. This work is under analysis. Towed hydrophone-array studies were also carried out during CHAIN Cruise 51, and noise-coherency calculations have been made with the data for a number of ship speeds.

Progress was made in the analysis of observations from previous cruises and in the completion of several scientific papers. For example, under the heading of Physical Oceanography we report the observation of large-scale, horizontal variations in acoustic structure which extend deep into the ocean between Bermuda and the Antilles. In addition, evidence from doppler shifts of internal waves relative to a moving ship indicate that internal waves are generated within the thermal front region located near 30°N latitude southwest of Bermuda.

In the field of Submarine Geology and Geophysics several invited papers were prepared and presented at the Upper Mantle Symposium at Ottawa. Although National Science Foundation Grant GP-822 paid for travel and preparation of these papers, some of the data were collected under other contracts, including those of the Office of Naval Research. Abstracts of these papers are included because of the appropriateness of the material to the interests of the ONR research program in Submarine Geology and Geophysics. For instance, correlation of gravity measurement over major submarine trenches and ridges seems to indicate that dense substratum material tends to rise beneath a trench or rift when the boundaries reach separations of 40 km - 100 km. These observations have major implications as to the interpretations of processes taking place within the upper mantle. This subject is also discussed under the gravity program.

The section on Submarine Geology and Geophysics also contains reports of progress in the analysis of gravity in the Ligurian Sea, seismic reflection profiles in the Puerto Rico Trench area, as well as other data analysis.

Dr. J. D. Phillips has recently joined the staff of the Geophysics Department. He is primarily interested in studying the magnetic susceptibility of marine sediments and the remanent magnetization in rock material dredged from the ocean floor. Some evidence from rocks dredged from the Mid-Atlantic Ridge supports the hypothesis that remanent magnetization is a major factor in oceanic magnetic anomalies. This research effort can provide important geophysical information. The research may also lead to an understanding of errors in headings determined from magnetic compasses on submarines operating close to the ocean floor where remanent magnetization is large.

Midwater fishes north of the thermal front near 30°N were found to be more abundant by a factor of four than those to the south of the front. This was in keeping with observations of midwater sound-scattering made at 12 kcps.

Another contribution discusses evidence for diffraction effects in RSR convergence zones in experiments in the Mediterranean Sea.

Efforts to analyze bottom reverberation from explosive shot data using a computer program is now in near-final stages. The computer program is now capable of taking account of noise corrections to bottom reverberation levels and computing scattering coefficients as functions of grazing angle. Progress in oblique bottom-reflection and in acoustic navigation are also described under the heading of Hydroacoustics.

Each major section also contains descriptions of progress on instrumentation and instrumentation techniques. Sea tests have been successfully carried out of automatic depth determination equipment designed to convert echo soundings into digital form for the shipboard computer. This system is described in Section B of the Submarine Geology and Geophysics Section. A section on General Instrumentation is included to allow for description of efforts, such as Sea Spider, and our shipboard data processing system.

Seven manuscripts have been published during this report period, a number of others have been submitted for publication. The titles are listed below. In addition, seven unpublished WHOI reports and six WHOI Technical Memoranda were completed and are also listed.

PAPERS

The following papers were published either under Contracts Nonr-4029(00), Nonr-1367(00), or in conjunction with other contracts or grants as noted:

WHOI Contr. No. 1387. The Geology of the Western Approaches of the English Channel. II. Geological Interpretation Aided by Boomer and Sparker Records, by D. Curry, J. B. Hersey, E. Martini, and W. F. Whittard, F. R. S., Philosophical Transactions of the Royal Society of London, Series B. Biological Sciences, No. 749, Vol. 248, pp. 315-351, 14 January 1965. (Contract Nonr-1367)

WHOI Contr. No. 1511. Navigational Techniques used in the THRESHER Search, by S. T. Knott. Navigation: Journal of the Institute of Navigation, Vol. 12, No. 1, pp. 3-10, Spring 1965. (Contract Nonr-4029)

WHOI Contr. No. 1527. Underwater Calls of Leptonychotes (Weddell Seals), by Wm. E. Schevill and Wm. A. Watkins. Zoologica (N. Y.) 50, pp. 45-46, 1965. (Contract Nonr-4029 and NSF G-141)

WHOI Contr. No. 1550. Underwater Call of Trichechus (Manatee), by Wm. E. Schevill and Wm. A. Watkins. Nature, Vol. 205, No. 4969, pp. 373-374, 23 January 1965. (Contract Nonr-4029)

WHOI Contr. No. 1565. A Shipboard Cable-Hauling System for Large Electrical Cables, by F. R. Hess and L. V. Slabaugh. Deep-Sea Research, Vol. 12, No. 4, pp. 537-539, 1965. (Contract Nonr-1367)

WHOI Contr. No. 1624. On the Existence of the Sea-Mount Known as "American Scout", by R. H. Backus and L. V. Worthington. Deep-Sea Research, Vol. 12, No. 4, pp. 457-461, August 1965. (Contracts Nonr-4029, Nonr-2196, NSF GB-543 and GS-861)

____________________. Improved Towline Design for Oceanography, by R. L. Rather, Vil Goerland, J. B. Hersey, A. C. Vine and Frances Dakin. Undersea Technology, Vol. 6, No. 5, pp. 57-63, May 1965. (Contract Nonr-4029)

The following papers were published during this period under other contracts; they are believed to be of interest to the Office of Naval Research:

WHOI Contr. No. 1437. Gular Musculature in Delphinids, by Barbara Lawrence and Wm. E. Schevill. Bulletin of the Museum of Comparative Zoology, Harvard University, Vol. 133, No. 1, pp. 1-65, May 1965. (Contracts Nonr Biology Branch and, NSF G-6171)

WHOI Contr. No. 1544. Behavior of Certain Marine Organisms During the Solar Eclipse of July 20, 1963, by Richard H. Backus, Robert C. Clark, Jr., and Asa S. Wing. Nature, Vol. 205, No. 4975, pp. 989-991, March 6, 1965. (Contracts Nonr-2196 and NSF GB-543)

______________. Some Long-Range Experiments on Sound Transmission, Correlation, and Reverberation, by Lincoln Baxter, Helen S. Graham and D. D. Caulfield. U. S. Navy Journal of Underwater Acoustics, Vol. 15, No. 1, pp. 15-40, January 1965. (CONFIDENTIAL) (Contract Nonr-2866)

The following papers were submitted either under Contracts Nonr-4029(00), Nonr-1367(00), or in conjunction with other contracts or grants as noted:

WHOI Contr. No. 1649. Continuous Seismic Profiles of the Outer Ridge and Nares Basin North of Puerto Rico, by Elizabeth T. Bunce and J. B. Hersey. Submitted to Bulletin of Geological Society of America. (Contracts Nonr-1367, Nonr-4029, and NSF G-822)

WHOI Contr. No. 1671. An Earthquake Recorded at Sea, by F. S. Birch. Submitted to Bulletin of Seismology Society of America. (Contract Nonr-4029)

WHOI Contr. No. 1674. Volcanic Rock from Caryn Seamount, by R. H. Feden. Submitted to Deep-Sea Research. (Contract Nonr-4029 and NSF GP-1123)

WHOI Contr. No. 1678. Classification of Sea Floor Sediments with a Shipborne Acoustical System, by L. R. Breslau. (Monaco). Submitted to La Revue Petroliere. (Contract Nonr-4029)

WHOI Contr. No. 1707. Ocean Drilling on the Continental Margin by JOIDES, by E. T. Bunce, K. O. Emery, R. D. Gerard, S. T. Knott, Louis Lidz, Tsunemasa Saito and John Schlee. Submitted to Science. (NSF G-4233 and Nonr-4029)

WHOI Contr. No. 1708. Heat Flow Measurements in the Altantic Ocean, Indian Ocean, Mediterranean Sea and Red Sea, by F. S. Birch and A. J. Halunen. Submitted to Journal of Geophysical Research. (Contract Nonr-4029, NSF GP-2370 and GP-1123)

WHOI Contr. No. 1718. The Puerto Rico Trench, by Elizabeth T. Bunce. Submitted to the Proceedings Volume of the Upper Mantle Symposia, Ottawa, Canada. (Contracts Nonr-1367, Nonr-4029, NSF GP-822 and NSF GP-1123)

WHOI Contr. No. 1752. Photographic Measurements of Bottom Currents, by J. G. Bruce and E. M. Thorndike. Submitted to Johns Hopkins University Press for publication in "Deep-Sea Photography". (Contract Nonr-4029)

WHOI Contr. No. 1761. Deep-Sea Photography in the Study of Fishes, by N. B. Marshall and D. Bourne. Submitted to Johns Hopkins University Press for publication in "Deep-Sea Photography". (Contracts Nonr-4029 and NSF GB-20702)

______________. Sound Reflections in and under Oceans, by J. B. Hersey. Submitted to Physics Today.

______________. Sparkers and Boomers, by J. B. Hersey. Submitted to Pergamon Press for publication in "International Dictionary of Geophysics".

The following papers were submitted during this period under related contracts as noted:

WHOI Contr. No. 1655. Identification of a Deep Sea Mooring-Cable Biter, by R. L. Haedrich. Submitted to Deep-Sea Research. (Predoctoral Fellowship)

WHOI Contr. No. 1670. Heat Flow near the New England Seamounts, by F. S. Birch. Submitted to Journal of Geophysical Research. (Contract NSF GE-1456)

UNPUBLISHED WHOI REPORTS

The following unpublished reports have been completed during this period under Contract Nonr-4029(00) or in conjunction with other contracts as noted:

WHOI Ref. No. 64-52. Final Report of Contract Nonr-1367 including a History of the Contract and the Bibliography of Scientific Contributions Supported by Contract Nonr-1367 at the Woods Hole Oceanographic Institution, 15 December 1953 - 31 August 1963, by J. B. Hersey. (Contract Nonr-1367, now Nonr-4029)

WHOI Ref. No. 64-53. Final Report of Contract Nonr-1367 including a History of the Contract and the Bibliography of Scientific Contributions Supported by Contract Nonr-1367 at the Woods Hole Oceanographic Institution, 15 December 1953 - 31 August 1963, by J. B. Hersey. (Contract Nonr-1367, now Nonr-4029) (CONFIDENTIAL)

WHOI Ref. No. 65-9. Narrative of CHAIN Cruise No. 43, February - August 1964, by S. T. Knott, E. T. Bunce, C. O. Bowin, J. B. Hersey, and R. L. Chase. (Contract Nonr-4029 and NSF GP-2370)

WHOI Ref. No. 65-15. Track Charts, Bathymetry and Location of Observations, ATLANTIS Cruise No. 260, North Atlantic Ocean, Hydrographers Canyon, Muir Seamount Surveys, 11 October - 7 November 1960, by R. M. Pratt and W. M. Dunkle. (Contract Nonr-1367, now Nonr-4029 and Nonr-2866)

WHOI Ref. No. 65-16. Narrative of CHAIN Cruise No. 38, 5-16 August 1963, by J. B. Hersey. (Contract Nonr-4029 and Nonr-2196)

The following unpublished reports completed under related contracts are deemed of interest to the Office of Naval Research:

WHOI Ref. No. 65-2. Bathymetric and Seismic Reflection Studies of the ARTEMIS Environs, by S. T. Knott. (Contract Nonr-2866) (CONFIDENTIAL)

WHOI Ref. No. 65-14. Track Charts, Bathymetry and Location of Observations, ATLANTIS Cruise No. 282, North Atlantic Ocean, 7 July - 11 August 1962, by J. S. Reitzel. (Contract Nonr-2866)

UNPUBLISHED WHOI TECHNICAL MEMORANDA

The following technical memoranda were completed during this period:

WHOI Tech. Memo 8-65. A Cable Clamp for Terminating Steel Cables with Conductors, by S. L. Stillman. (Contract Nonr-4029)

WHOI Tech. Memo 9-65. A Manual Explaining the Theory and Operation of Heat-Flow Measuring Equipment, by Francis S. Birch. (Contract Nonr-4029)

WHOI Tech. Memo 10-65. Cruise Plan for Project Sea Spider, Cruise Plans for CHAIN No. 51 and GOSNOLD No. 73, 15 July - 30 August 1965, by G. H. Savage, J. C. Beckerle and J. B. Hersey. (Contract Nonr-4029)

WHOI Tech. Memo 11-65. Cruise Plans for CHAIN Cruise No. 52, 20 September - 8 October, 1965, by E. F. K. Zarudzki. (Contract Nonr-4029)

WHOI Tech. Memo 12-65. Cruise Plans for CHAIN Cruise No. 55 to Western Caribbean, 10 November 1965 - 20 December 1965, by C. O. Bowin. (Contract Nonr-4029)

WHOI Tech. Memo 13-65. Cruise Plans for CHAIN Cruise No. 53, 14 October - 27 October 1965, by S. T. Knott. (Contract Nonr-4029)

CRUISES

A. Introduction

The principal vessel from which the Department of Geophysics conducts research is the R/V CHAIN. During this report period this ship was used on three separate cruises totaling about two months at sea. These cruises were supported wholly by Contract Nonr-4029. The contract also supported the use of GOSNOLD in the region of the Blake Plateau for approximately one month, which was required for assistance to CHAIN Cruise 51.

B. Use of Vessels

Cruise No. and Sponsor	Date	Work Area	Principal Investigations	Chief Scientist
CHAIN 51 Nonr-4029	30 July - 31 Aug. 1965	Atlantic Ocean Blake Plateau, 30°15'N-78°40'W	Sea Spider, a multimoored buoyant structure; measurements of movement of buoyant structure; acoustical navigation tests; seismic profiling, temperature, current and sound velocity profiles.	G. H. Savage J. C. Beckerle J. B. Hersey
CHAIN 52 Nonr-4029	21 Sept. - 8 Oct. 1965	Blake Plateau Area, Blake Arch, Blake Spur, Florida-Hatteras Slope 30°15'N-32°50'N	Seismic profiling, dredging, and coring	E. F. K. Zarudzki
CHAIN 53 Nonr-4029	14 Oct. - 27 Oct. 1965	Hatteras Abyssal Plain 28°49'N-70°50'W	Oblique and vertical seismic reflections using a radio buoy, seismic profiling, coring, sound velocity profiles, and magnetic and gravity measurements.	S. T. Knott
GOSNOLD 73 Nonr-4029	9 July - 5 Aug. 1965	Blake Plateau 30°15'N-78°40'W	Suitable site for Sea Spider, topographic survey, current measurements, setting marker buoy.	A. Erickson

C. <u>CHAIN Cruise #51</u> (Mr. Savage, Dr. Beckerle, Dr. Hersey, and Mr. Zarudzki)

This cruise of CHAIN left Woods Hole on July 22 for the Blake Plateau for the ocean tests of Sea Spider. CHAIN returned to Woods Hole on August 31, 1965. The scientific and engineering aspects of this cruise are described in several places throughout this report. The reader is referred to the General Instrumentation Section for an account of Project Sea Spider and further description of this cruise.

D. <u>CHAIN Cruise #52</u> (Mr. Zarudzki)

CHAIN Cruise #52, to the Blake Plateau, was mounted both to expand the seismic reflection, gravity, and magnetic coverage of the area, and to look at certain details. The principal areas of interest were: the Florida-Hatteras Slope of the Blake Plateau lying between 30°15'N and 32°50'N, the Blake Spur (30°N, 76°30'W), and the Blake Arch (28°30'N to 33°30'N, 72°W to 77°W). The two last features are so named on the latest U. S. Geological Survey Miscellaneous Geologic Inventory Map I-451, sheet 1 and 2. They sometimes have been referred to by other writers as the Blake Nose and the Cape Fear Arch.

The chief objective of the investigation was the study of the extent and implications of the deposits transgressing eastward over the Blake Plateau. This phenomenon was noted by us during CHAIN Cruise #51 in the area about 80 miles SSW of Charleston, S. C. During that cruise three seismic reflection profiles were obtained which clearly showed the recent deposits progressively encroaching upon the current-scoured floor of the Blake Plateau. Of primary importance in this study is the apparent eastward displacement of the Gulf Stream, and the implications of this discovery upon the study of the Stream's behavior. In this sense CHAIN Cruise #52 was the follow-up of the original discovery.

The Blake Spur had been investigated by previous researchers (Woods Hole Oceanographic Institution and Lamont Geological Observatory) and it was felt that an additional study of this unusual feature would further elucidate its structure, past history, and possible effect on ocean currents and sediment deposition.

The Blake Ridge is a feature of over 2,000 meters relief, and is roughly triangular in plan. It abutts the Blake Plateau Escarpment, its axis trending SE, and is aligned with the geologically well-known Cape Fear structural arch. The structure and the origin of the ridge are speculative at present. So far, an inadequate amount of seismic reflection profiling is available for deriving clear conclusions. A series of deep-penetration seismic profiles, run simultaneously with the gravity and magnetic profiles was designed to increase our knowledge of this feature.

A problem of paramount importance is whether the vast ridge is formed as a sedimentary feature with, or without, structural control provided by the ocean floor. Some researchers believe that such a feature could be formed at the convergence of the north-east flowing sediment-charged part of the Gulf Stream with a deep south-west flowing coastal current.

Other objectives of the cruise were to obtain seismic reflection profiles across the continental slope and rise en route to the Blake Plateau, and continuous gravity and magnetic profiles between Woods Hole and the Blake Ridge. Bottom photography and dredging for bottom samples were to be made in areas of interest. Those were the top and flanks of Blake Spur, selected locations on the Blake Plateau paralleling and immediately in front of the continental slope, and finally on the crest and flanks of the Blake Ridge.

The cruise began on September 21, 1965 and ended on October 8, 1965. Objectives were achieved to a large degree. In all, 1510 miles of seismic reflection profiles, 2310 miles of gravity profiles and 2200 miles of magnetic profiles were obtained. Five camera stations and eight dredge stations were occupied.

E. <u>CHAIN Cruise #53</u> (Mr. Knott)

The objective of this cruise, from 14 to 27 October 1965, was to obtain measurements of the acoustic energy from a broad band source reflected from the sea floor over both vertical and oblique paths in order to study the reflectivity of the sea-floor as a function of angle of incidence and of sound frequency. An operating area on the Hatteras Abyssal Plain having apparently quite uniform sediments was chosen to simplify and make control of the experiment easier. An underwater spark was used as a sound source for both vertical and oblique seismic reflection measurements, and 12-kc sounding equipment was used for the vertical monofrequency measurements taken simultaneously with those above. Vertical seismic reflections were received by a five-element array of Chesapeake type PC 100 transducers which were so connected that signals could be received by single elements or by the array as a whole. Oblique reflections were received at a Brush AX120 hydrophone mounted 1000 feet from the sea surface on the taut-line mooring of a reference buoy and signals were transmitted by radio-link to the ship. The hydrophone was placed at a depth of 1000 feet so that bottom reflection signals were completely received before the corresponding surface reflected signals were received.

Gravity, magnetic, and bathymetric profiles were obtained between Woods Hole and the buoy location on the Hatteras Abyssal Plain over south-bound and northbound tracks on the meridians 70°30'W and 70°50'W, respectively. Continuous seismic reflection profiles were taken over parts of the continental rise and lower slope south of New England, and over a grid of tracks at the buoy location.

Measurements of the velocity of sound in the water column, bottom photographs, and core samples of the sediments were to be taken at the buoy location to supplement reflectivity observations. Although heavy weather reduced working time on station by a factor of two, the following was accomplished:

1. The reference buoy was moored at 28°49'N, 70°49'W, in 2867 fathoms. A tension of at least 2000 pounds was achieved at the anchor end of the mooring-line (See the General Instrumentation Section, p. 58 of this report). The mooring held successfully throughout the three-day period during the later part of which a sea state of 6 existed for some 15 to 20 hours. The maximum total scope of the buoy was determined on several separate occasions during the experiments to be about 0.2 nautical mile. A combination of visual bearings of the buoy from the ship and Loran-C fixes was used for these measurements. Continuous monitoring of the buoy's position was not possible because of the number of times that Loran shore stations indicated trouble, the failures in our Loran-C receiver, and the lack of proper visibility for bearing determinations. Our radar had failed earlier in heavy weather.

2. A series of three, oblique seismic-reflection runs were made over a grid of tracks in a 5 by 8 mile area immediately west of the buoy. During these runs periodic measurements of the vertical reflections were made with the 12-kc sounder and with single hydrophones in the array.

3. Three velocimeter profiles were made across the area.

4. Four short (1 to 2-foot) cores were obtained with free-fall corers. Locations of the cores were distributed along the north-south axis of the area.

5. High resolution echo-sounding records were taken whenever possible, especially in the immediate vicinity of the buoy, in order to determine the extent of shallow stratified reflecting surfaces below the seafloor.

6. Vertical reflection measurements over the grid at the buoy reveal an extensive sequence of reflectors from the shallow stratification to a deep, moderately rough and strong reflector some 1.7 to 2.0 seconds or more (reflection travel-time) below the sea floor.

PHYSICAL OCEANOGRAPHY

A. Investigation and Analysis

Sound Velocity Contours Northeast of the Bahamas (Dr. Beckerle and Mr. Payne)

Seventy-three sound velocity profiles were obtained during Cruise 11 of R/V ATLANTIS II in the water southwest of Bermuda in July - August 1964. The method of determining the depth of the velocimeter makes use of an inverted echo sounder that measures the round trip acoustic travel time between the sound velocimeter and the ocean surface once every second. The measurements of the local sound velocity as function of the acoustic travel time are used in a computer to calculate the depth of the instrument throughout the sound velocity profile. The high accuracy and reliability of this technique provides confidence in comparing the measured values of the sound velocity at a specific depth for the many profile stations.

The geographical variation of the sound velocity at a depth of 800 meters is shown by contours in meters/second as deviations about 1500 meters/second over a broad stretch of the Atlantic Ocean in Figure 1. The contours in the figure, which were drawn by Mr. Zarudzki, exhibit several interesting features. For instance, northeast of the Bahamas there is evidence of a spatial variation in sound velocity, having an average wavelength of about 240 nautical miles. These variations are believed to be the interference of long Rossby waves reflecting from the Bahama Platform. This possibility is under consideration in plans for future experiments. In addition, there appears to be a region of low sound velocity labelled -2 meters/second, at about 24°N, 67°W that is surrounded on all sides by higher sound velocity contours. There is evidence in the figure of the deep thermal front region (transition region) located near 30°N which was reported in last year's Summary of Investigations (Beckerle, 1964). Similar contour charts have been prepared for a number of depths and they will be included in a manuscript that is being prepared for publication.

<u>Evidence of Internal Waves in Crossing the Thermal Front Region</u> (Dr. Beckerle)

Experiments were carried out during the April 1965 cruise of the CHAIN to determine whether or not the thermal front region about 120 miles southwest of Bermuda was a source of internal waves and to obtain information to aid in planning acoustical transmission experiments across the region. The study was made by towing a sound velocimeter at a constant depth across the frontal zone several times to determine whether or not spatial frequencies of internal wave fluctuations on one side of the front differed from those on the other side.

A striking feature of the sound velocity fluctuations in crossing the frontal region were several step-like changes with the maximum sound velocity occurring near the center of the region. During each crossing there was a large set in the track of the ship, although the heading and speed of the ship were held constant. This observation implies the existence of strong cross currents delineating the frontal region. The observations are presented in Figure 2.

A conjecture was made prior to this experiment that internal waves should be generated at the thermal front (Beckerle, 1965). In this event one would expect to observe a higher spatial frequency when the ship was moving opposite to their direction of propagation, that is toward the

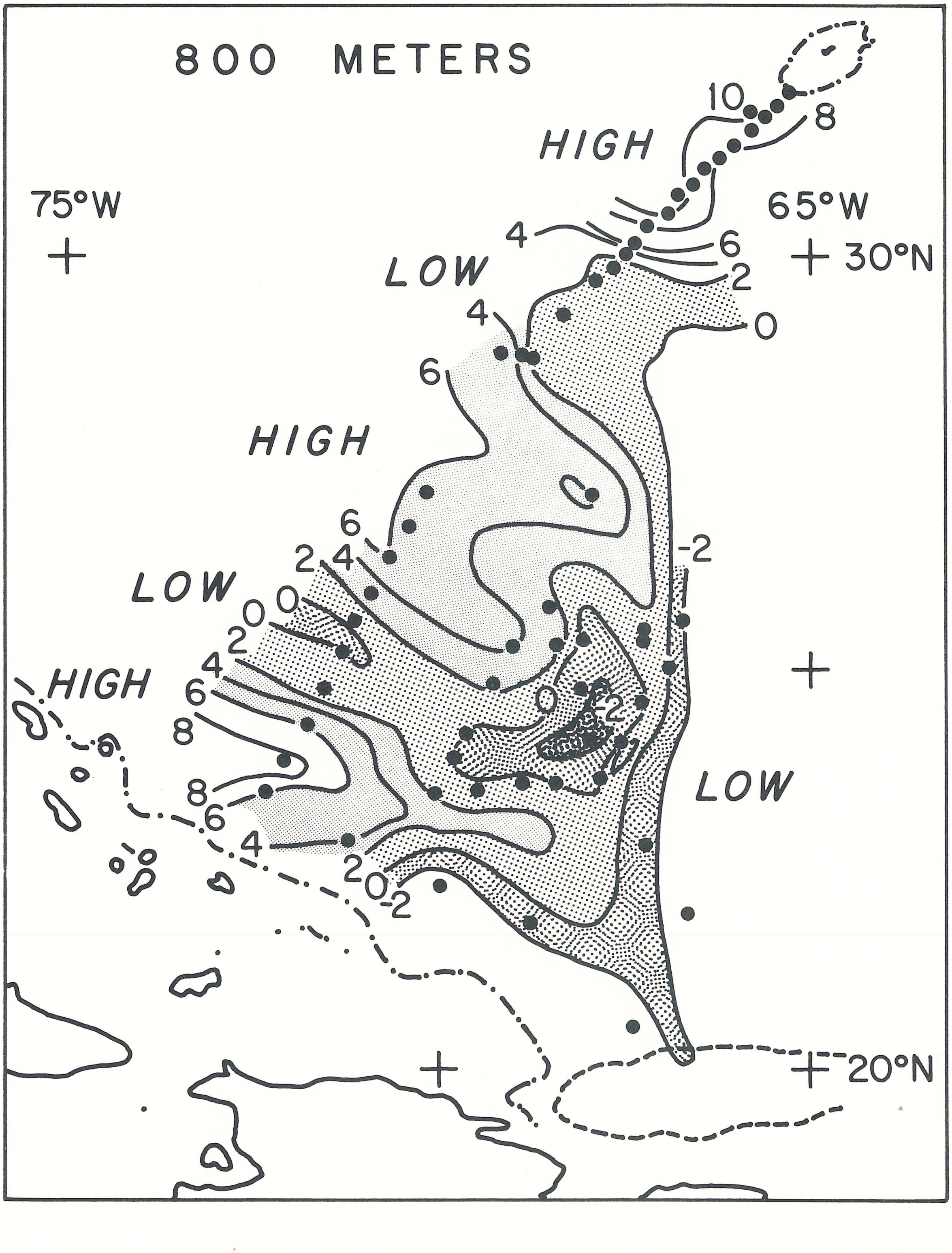


Figure 1. Sound velocity contours at 800 meters depth as deviations, in meters/sec about 1500 meters/sec.

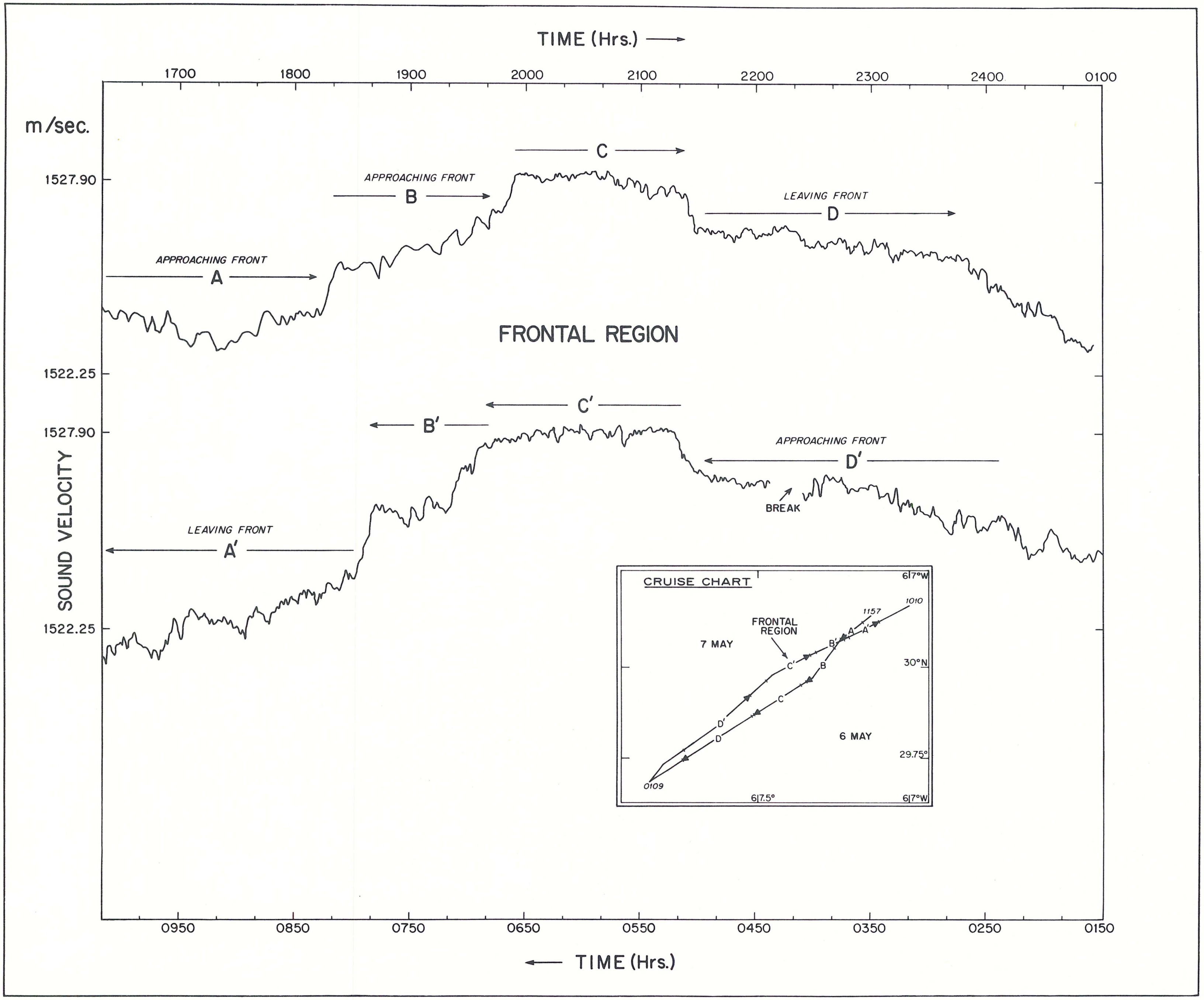


Figure 2. Towed Sound-Velocimeter Recording.

thermal front, and a lower spatial frequency when moving away from the front. An examination of the measurements from the towed sound velocimeter indicated just the opposite. This doppler effect in the sound velocity fluctuations is easily observed in Figure 2. For example, there is a lower spatial frequency in the region A and B of the top record relative to regions A' and B' of the bottom record and also relative to the region C and D in the top record. A doppler shift could explain these observations if the advancing phases of the internal waves were moving toward the thermal front from both sides; i. e., the thermal front was a sink for the internal waves rather than a source.

Variations in Sound Velocity on the Blake Plateau (Mr. Payne, Mr. Stillman and Dr. Beckerle)

On Cruise 51 of the R/V CHAIN twenty-seven sound velocity profiles were obtained within a five-mile radius of the Sea Spider buoy at 30°15'N, 78°40'W on the Blake Plateau during the period 26 July to 23 August 1965.

Depths accurate to ±1 meter were calculated from these data and aided in the anchoring of the Sea Spider buoy. The Sea Spider location is near a boundary between Areas 13 and 14 outlined in Matthews' Tables. Depths of the ocean bottom calculated with the use of Matthews' Tables differ from those calculated from the sound-velocity profile measurements by 2. 5 m to 8. 5 m depending on which area, 13 or 14, one assumes includes the buoy.

The mean velocity (over vertical travel time), calculated from four lowerings during the 24 hours that measurements were made on the motion of the buoy, showed that the small variations observed in acoustic travel times from the bottom-mounted pinger to the Sea Spider hydrophone could not be accounted for by variations in the sound velocity. (For further discussion see "Acoustic Measurement of the Motion of Sea Spider" in Hydroacoustics, Section B.)

Initial profiles revealed a three-layer water structure which, however, changed markedly during the period of observation. In spite of these changes the harmonic mean velocity remained remarkably constant.

A recording obtained from a current meter attached to the Sea Spider buoy showed a significant variation which we hope to correlate with fluctuations in sound velocity profiles made during the time the meter was operating.

The Ray Theory of Internal Waves and Temperature Measurements in the Ocean (Dr. Beckerle)

During the towed thermistor-string experiments of July 1964 from ATLANTIS II, one thermistor in the string was set in the isothermal water at the knee of the temperature-depth profile. The intention was to detect the depth variations of the top of the thermocline along the ship's track. In the waters approaching the Gulf Stream from the south, on a course from Bermuda to Woods Hole, temperature fluctuations were observed which resembled level fluctuations of acoustic bottom-reflected signals from explosive shots. Of course, the time scale and the method of recording the temperature fluctuations were entirely different. A typical temperature recording is shown in Figure 3. In this figure, a drop in temperature at the thermistor, which results from the upward movement of colder water from below, corresponds to an upward deflection on the recording. The temperature fluctuations along the ship's track are made up of a series of pulse-like variations, with each successive pulse reaching greater amplitude and having greater width. In view of their appearance, the writer supposed that a ray theory for internal wave propagation might be useful in describing the observations. A ray approach to internal waves was found in the works of Eckart (1960). Preliminary interpretations of this theory appear to be able to explain portions of the observations. Since these observations were made, similar temperature fluctuations have been found on other towed thermistor-string measurements.

B. Oceanographic Instrumentation

Towed Thermistor Equipment (Mr. Tasko and Mr. Boutin)

An objective in the continuing development of thermal-structure profiling equipment (the thermistor string) is the provision for analysis of the measurements by computers. Both on-line analysis through the use of shipboard computers and immediate visual presentation of the results are required.

At present, the system consists of equipment for continuously scanning and recording all points in a 52-station thermistor cable with an active length of 208 meters; eventually, the thermistor string will be extended to

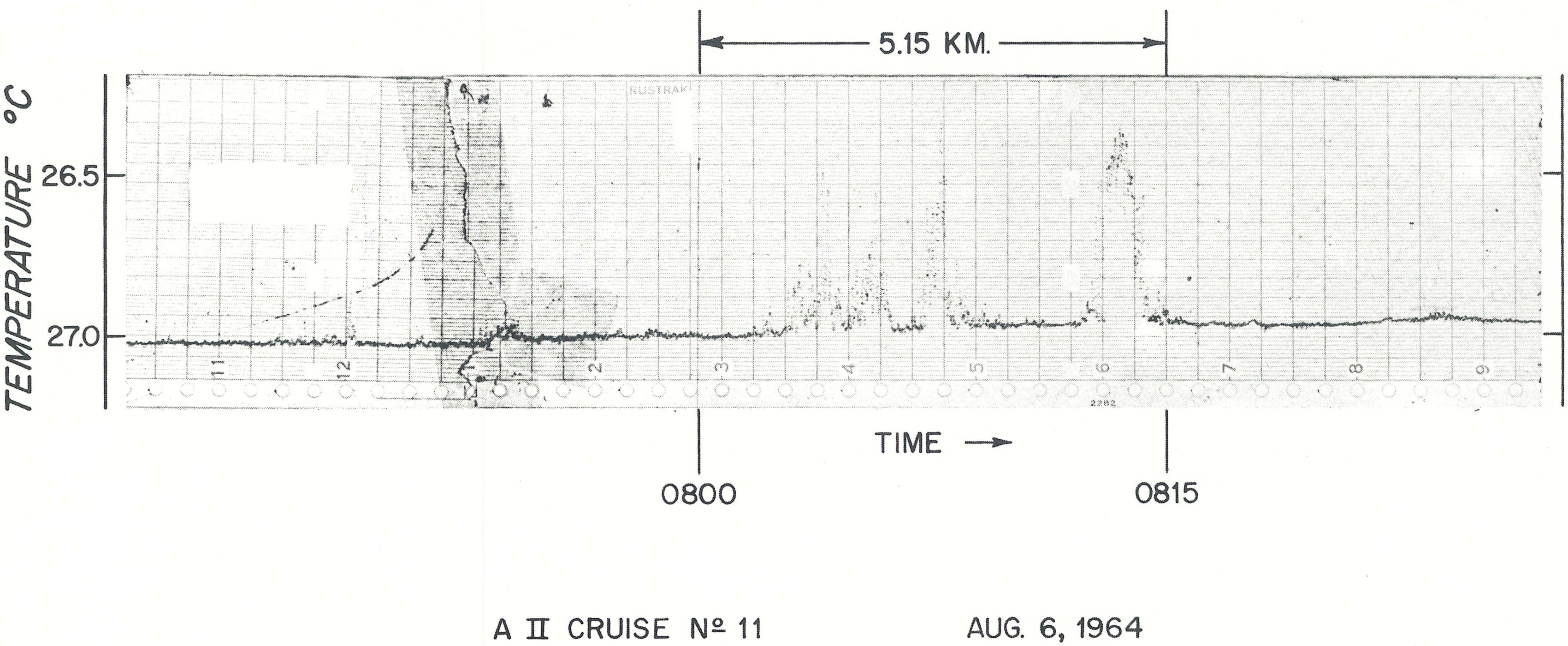


Figure 3. Towed Thermistor Recording.

depths of 1500 meters or more. As in the system designed by Hubbard and Richardson (1959), a continuous contour temperature recorder (analog presentation) will be used to display the thermal structure profile for immediate shipboard interpretation and guidance in data gathering. Each individual temperature measurement is now stored digitally on magnetic tape. Digital techniques are also being applied in other parts of the system outlined in the block diagram, Figure 4. Those parts of the system worked on in this report period are shown in the dashed lines. Solid lines indicate completed portions of the total system. Dotted lines represent anticipated future expansion of the system.

The digital-to-analog converter is being incorporated into the system as shown in the diagram. Synchronization of the scanning mechanism of the analog recorder to the scanning program of the digital equipment has presented several problems. A low-inertia stepping-motor system was first tried as a drive for the helix drum of the recorder, but because the helix drum would not respond properly to the step by step delivery of torque, the design has been altered to a continuous drive mode. System modifications to allow for this change are being made.

Polyurethane was used as a waterproof jacket for the towed cable because of its excellent wear characteristics as previously reported. However, difficulties were encountered at the individual thermistor stations in bonding polyurethane to connector pins at the base of the thermistor sockets. Besides these problems, there was difficulty in molding a urethane station on the cable without causing air from the cable's interior to bubble out. This resulted in a small porous region at splices which would leak under pressure.

Aluminum cable fairings lined with polyurethane to reduce chafing of the electrical cable and the strain member are being tested. Marked reductions in abrasion and in tow noise have been observed in these tests.

<u>An Improved Keel-Depth Temperature Measuring System</u> (Mr. Tasko and Mr. Boutin)

The thermistor mounted at the bow of the R/V CHAIN has proved to be unsatisfactory for quantitative keel-depth temperature measurements.

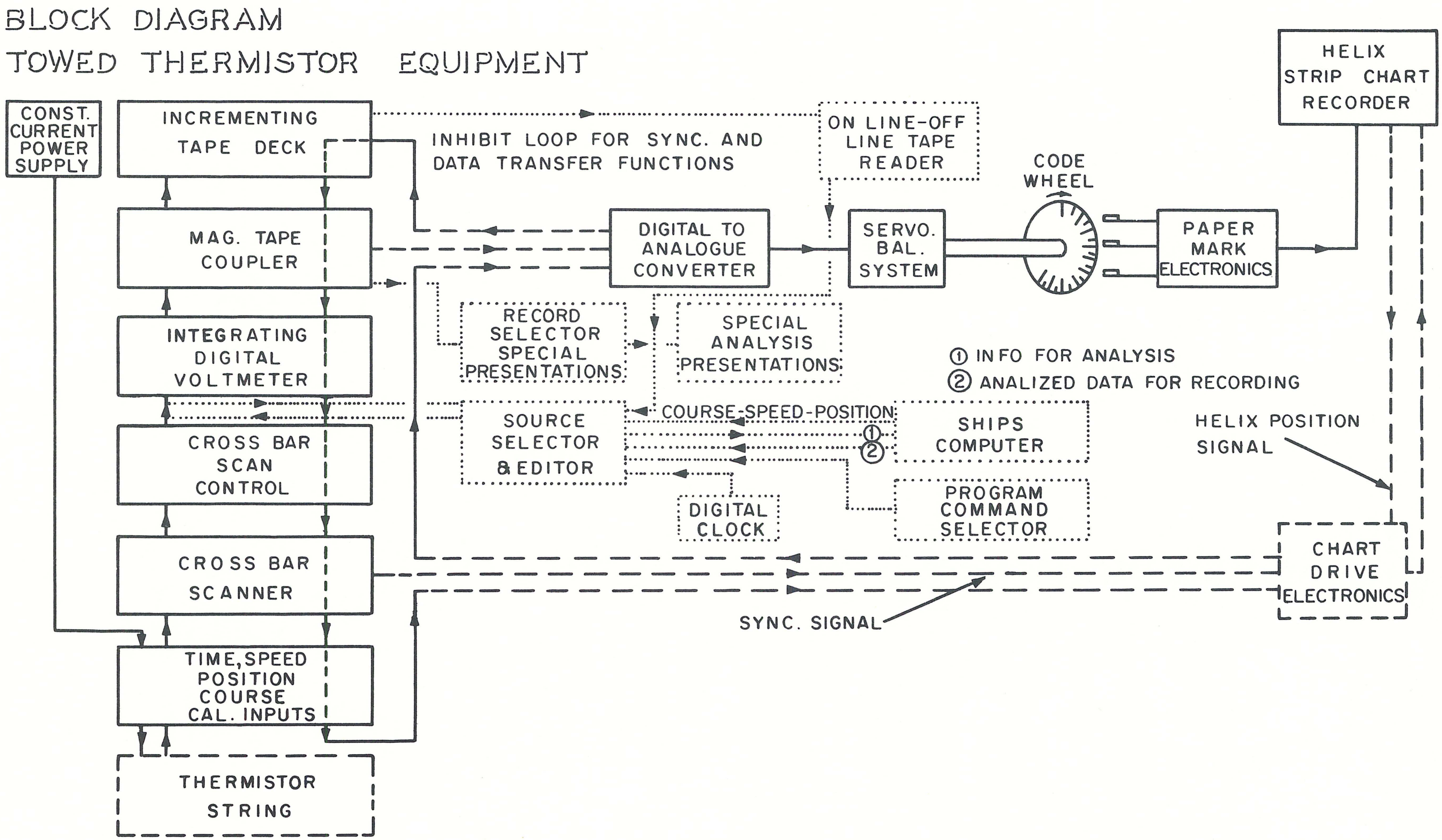


Figure 4. Block diagram of towed thermistor equipment.

Although such phenomena as thermal fronts could be detected, accurate measurements of temperature and calibrations of the thermistor were impractical. A new system using a quartz thermometer has been built into a pit-log shaped sword installed through a pit-log-sword gland in the hull of R/V CHAIN. Both an analog recording and a digital output to the shipboard computer for storage are now provided, and an accurate digital display is used to calibrate the analog presentation. The system is sufficiently accurate to be used as a reference standard and can be calibrated throughout its entire range by one measurement since the sensing device is, by its very nature, almost linear and its curve cannot change with age.

Velocimeter System (Mr. Stillman, Mr. Payne and Dr. Beckerle)

Efforts continue to improve the reliability of the sound velocimeter system and to make the system compatible with the computer at sea for calculation of sound-velocity profiles during each lowering. For instance, in a laboratory set-up of the velocimeter system, adjustments and modifications were made to the inverted echo sounder which resulted in substantial improvement in the system signal-to-noise ratio. This effort is directed toward the eventual use of a counter to measure the round-trip acoustic travel time between the instrument package and the sea surface during a lowering. The counter output will directly feed the digital computer on our research vessel with these measurements. We were also able to reduce third-harmonic noise from the sound-velocimeter signal which could be observed in the band centered at 12-kc used for the reception of the inverted echo-sounder signal. During CHAIN Cruise #53 efforts were made to reduce noises arising from the winch. Besides slip-ring noises generated by the winch, some of the winch noise observed in the echo-sounder signal apparently results from the application of the winch brake. Braking is applied frequently by the winch operator to maintain a constant rate of descent of the instrument.

Frequent calibrations are made of sound velocimeters in order to obtain information about the accuracy of these instruments. Recently a velocimeter was sent to us from the Hudson Laboratories' group in order to be calibrated by our techniques.

SUBMARINE GEOLOGY AND GEOPHYSICS

A. Investigations of Geographical Areas

Report on International Upper Mantle Symposium (Dr. Bowin, Miss Bunce, Dr. Hersey and Mr. Knott)

Four members of the department, Dr. Hersey, Miss Bunce, Dr. Bowin, and Mr. Knott, participated in and presented invited papers at the International Upper Mantle Symposia held at Ottawa, Canada, in September 1965. This participation was supported by Research Grant GP-822 of the National Science Foundation. Investigations reviewed and reported in the papers have been supported by the National Science Foundation and the Office of Naval Research. Since they are clearly of interest to the Office of Naval Research they are reported here in abstract form.

Abstract

Gravity over Trenches and Rifts
Carl O. Bowin

Mid-ocean ridges and the deep trenches are the most prominent features of the ocean basins, and both have been explained by investigators as owing to convection in the mantle. Some aspects of these interpretations are examined. The ridges are in nearly isostatic equilibrium (free-air anomaly values are generally less than 50 mgals), but the trenches have very large negative free-air anomaly values and are considerably out of isostatic equilibrium. The Puerto Rico Trench has the largest free-air anomaly so far measured on the earth's surface (-380 mgals). The Cayman Trough in the Caribbean Sea, although of similar dimensions in plan to the Puerto Rico Trench, has a sea Bouguer anomaly high over the trough and thus compares more closely with troughs such as the Red Sea and the Gulf of California. A comparison of the Gulf of Aqaba, the East African Rifts, the Red Sea, the Gulf of California, and the Cayman Trough is made.

Assuming a tensional origin for these features, it is concluded that between 40 and 100 kms of separation appear to be necessary before dense substratum begins to rise upward beneath the trough or rift.

Abstract

The Puerto Rico Trench
Elizabeth T. Bunce

The results of recent marine geophysical investigations have been integrated with those of several earlier studies in an effort to define the structure of the Puerto Rico Trench. The observations include seismic refraction and continuous seismic reflection profiles, measurements of free-air gravity anomaly, and bathymetry.

The floor of the Trench is an abyssal plain 8. 3 km deep (depth corrected for velocity of sound), sloping gently to the south. The shallow layers of the sea floor revealed by short-pulse echo sounding are uniform across the axis but thicken towards the western boundary. The deeper sedimentary layers both tilt and thicken to the south. A continuous reflection profile approximately along the axis of the Trench shows between 1. 5 and 2. 0 km of layered sediments overlying a rough basement surface. The basement rises to north and south, forming the slopes that bound the plain. The crustal structure section shows a difference in the compressional wave velocities of material underlying the Trench and the Outer Ridge.

Much of the seismic activity of the area is located beneath the south slope and occurs as shallow-focus earthquakes. The minimum free-air gravity anomaly is displaced from the axis of the Trench toward the south slope. The Trench may be a downfaulted or downwarped structure with activity continuing along the southern margin.

An acoustically transparent sediment layer beneath the bottom reflection can be traced in places continuously down the north slope and beneath the upper section of abyssal plain sediments. The formation of the Trench thus post-dates this layer.

Recent dredge hauls on the north slope have obtained Eocene rocks from this layer. Thus the age of deformation of the Trench may be as recent as Eocene.

Abstract

Geophysical Investigations in the Eastern Caribbean Sea Area
J. B. Hersey

The ocean area between northeastern South America and the Nares Deep has been the object of intensive gravity, seismic, and bathymetric investigations since 1930. The early gravity observations of Vening-Meinesz, Ewing, and Hess here and in the East Indies stimulated two decades of theorizing about the structure of Island arcs and foredeeps. The seismic refraction studies of the late forties and fifties have shown that the Nares Deep and adjacent outer ridge have the characteristic thin crustal layer and associated structures of typical ocean basins. The Caribbean Sea has a slightly thicker crust, consisting of two layers, a shallower one of 6.0-6.7 km/sec compressional wave velocity and a deeper one of 7.0-7.5 km/sec. The crustal layer deepens and is overlain by a complex suite of layers having lower velocities in both greater and lesser Antilles and beneath the foredeep.

Since 1960 seismic reflection profiling over the Nares Deep, the Outer Ridge and the Puerto Rico Trench have revealed detail in the associated low velocity layers which corroborate earlier refraction observations and show two contrasting bodies of stratified sediment and rock. These lie unconformably on a surface of high relief which corresponds to the top of the 5.2-5.5 km/sec layer (just above the crustal layer 6.5-6.7 km/sec). The shallowest major group of sediments, called the transparent layer appears to be older than the formation of the Trench. Its topography, structure, and distribution suggest that it may be the remnant of a continental rise which formed northward from Puerto Rico before the Puerto Rico Trench existed.

Abstract

Red Sea Seismic Reflection Studies
S. T. Knott, E. T. Bunce and R. L. Chase

Seven continuous seismic reflection profiles were made across the main trough of the Red Sea north of 17°N latitude. These were accompanied by short-pulse echo-soundings and measurements of the total intensity magnetic field and the free-air gravity anomaly.

The horst-and-graben structure of the Gulf of Suez continues southward beneath the western marginal zone of the main trough at least as far as latitude 20°05'N. Deformation of sediments in the grabens indicates fault activity during and after deposition. Short-pulse echo-soundings reveal several episodes of faulting, probably Pleistocene, in the top 20 meters of subbottom sediments in the Gulf of Suez.

The main trough between the shelves of the Red Sea can be divided into mildly deformed marginal zones and a deeper, intensely fractured axial zone. Sedimentary sequences in places over 1.8 km thick are found in the marginal zones. Sediment-filled depressions in the western marginal zone at latitudes 18° and 25°N appear to be basins partially closed at their eastern margins by buried blocks of crystalline basement. A strong reflector 0 to 500 meters below all zones of the main trough is postulated to be an unconformity of late Miocene or early Pliocene age. If this postulate is correct, the following can be stated about ages of deformation in the main trough: (1) Most of the deformation in the axial zone appears to have taken place (a) before the beginning of the Pliocene and (b) late in Plio-Quaternary times. These periods of deformation were separated by a period of tectonic quiescence during the early part of Plio-Quaternary time. (2) In the marginal zones, horsts and sediment-filled grabens similar to those of the Gulf of Suez were formed before the Pliocene, and lie buried beneath little-disturbed sediments of Pliocene and younger age.

Recently deposited layered sediment ponds exist in the north and south ends of the Red Sea.

<u>Analysis of Seismic Reflection Profiles of the Puerto Rico Trench</u> (Dr. Chase and Dr. Hersey)

Continuous seismic-reflection profiles taken in 1962 and 1964 during Cruise 34 of the R/V CHAIN and Cruise 11 of the R/V ATLANTIS II were analyzed to find evidence of the mode of origin of the present topography of the North Slope, sometimes called the North Wall, of the Puerto Rico Trench. This study is part of a larger study of the rocks, topography, and structure of the Trench and Outer Ridge.

The echo-sounding records of the North Slope were used in the production of natural-scale profiles of uncorrected depths. These profiles were corrected for the velocity of sound in water by use of the tables of Matthews (1939). Slopes were then corrected by the method of swinging arcs (Officer, 1954), and subbottom acoustic reflectors appearing on the reflection profiles were plotted beneath the corrected bottom surface. The velocity of compressional waves in the sediments between bottom and reflectors was taken from the refraction studies of Bunce and Fahlquist (1962) and used to convert travel time to depth for the reflectors.

The completed natural-scale seismic reflection profiles reveal that the Trench is bounded to the north not by a "wall", as seems evident from the vertically exaggerated profiles usually resorted to, but a slope of average inclination of about 3 degrees. The slope is broken in many places, however, by steep scarps, flat plains and even reverse scarps. This topography expresses the complex geologic processes by which the North Slope was formed. On the basis of the profiles, it is postulated that more than one mechanism could be responsible for the topography of the North Slope of the Trench. Previously, normal faulting had been considered as a mechanism and used to support the hypothesis of tensional origin of the Trench. However, gravity sliding and transcurrent faulting appear equally feasible mechanisms.

<u>Seismic Reflection Profiles on the Continental Boundary off Jacksonville, Florida</u> (Mr. Knott and Miss Bunce)

During the return voyage to Woods Hole of R/V CHAIN (Cruise 46) (WHOI Reference No. 65-46, p. 12) two reflection profiles extending across the continental shelf to the Blake Plateau were made at the request of the JOIDES Committee prior to the drilling operations in this area. The results of this work are included in the report "Ocean Drilling on the Continental Margin", submitted to <u>Science</u> for publication and presently in press. They are summarized here and in Figure 5. The prominent reflector (A) found on both profiles continues beneath the shelf and slope to become part of the sea floor at the foot of the slope. It is tentatively identified as of Paleocene age. The two reflectors identified as (B) and (C) may correspond to the top of deposits of Upper Eocene and Middle Eocene age, respectively. A primary inference to be drawn from these data is that major faults between the continental shelf and Blake Plateau structures are not evident.

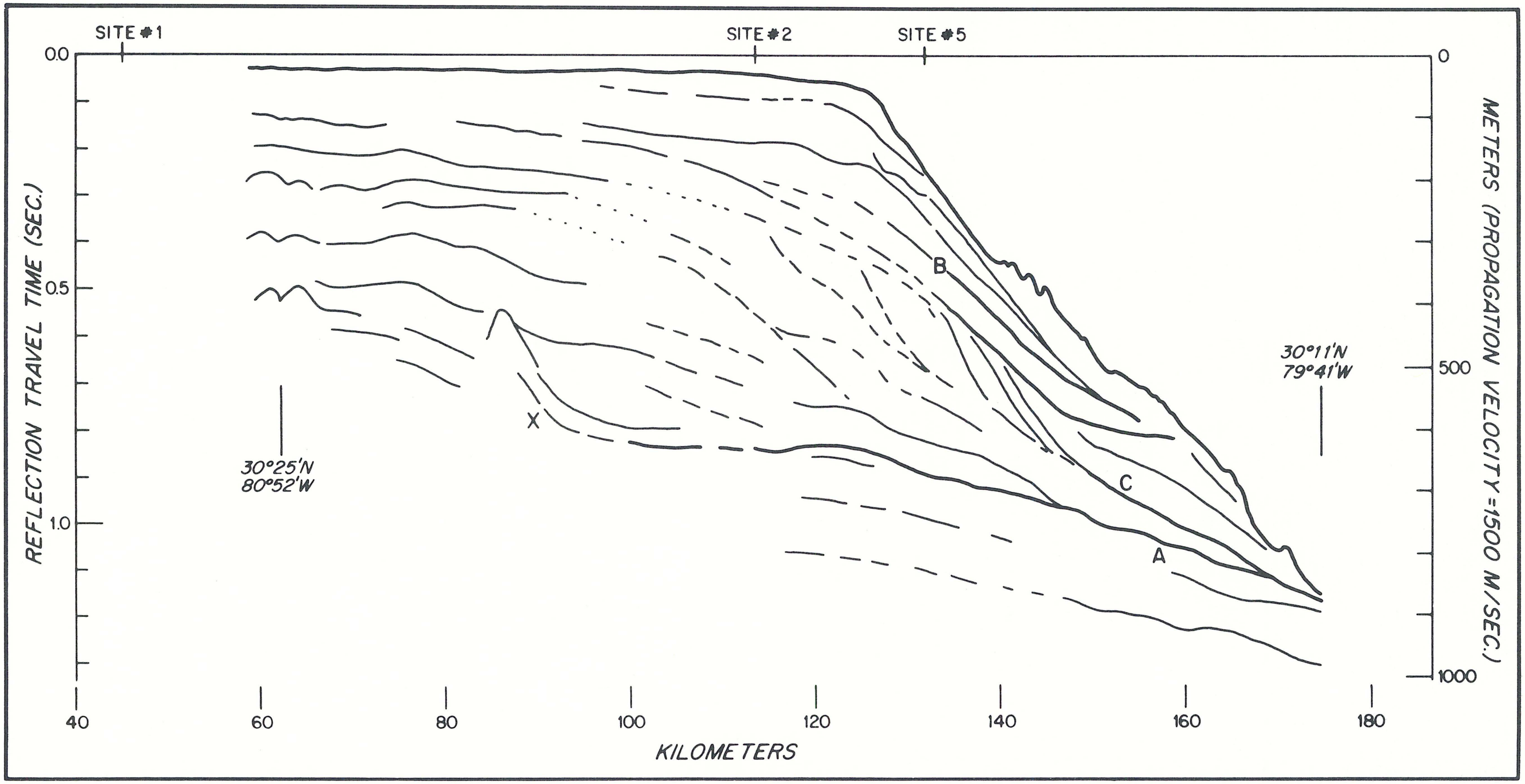


Figure 5. Composite tracing of the continuous seismic profiles run from JOIDES' Hole 1 to the foot of the continental slope. Line width indicates relative reflection strength. The horizontal scale represents the distance in km from the Fernandina Beach site, at 30°38'N, 81°27'W. Topographic exaggeration is 67. (c=1500 m/sec).

Blake Plateau Seismic Reflection Observations (Mr. Zarudzki)

Refer to report on R/V CHAIN Cruise 52 in the Cruise Section.

Bathymetric, Gravimetric and Magnetic Studies in the Ligurian Sea (Dr. Hersey, Mr. Zarudzki, Mr. Hodgkins, and Miss Atwater)

The interpretation of the geophysical data recorded in the Ligurian Sea during the CHAIN Cruise 43 (WHOI Reference No. 65-12, p. 34 and Reference No. 65-46, p. 24) continued during the latter part of 1965.

The continuous seismic profiles were qualitatively reviewed and the decision was made to reproduce, by replaying the magnetic tape, about 25% of the total seismic coverage, in order to enhance the observed deep reflections.

To determine the best possible playback band-passes, a frequency analysis of the reflection spectra was initiated. Twelve sample areas were chosen and a Sanborn recorder system was tried as well as photographic techniques of frequency analysis. The latter was found more effective. The technique utilizes an endless tape upon which the signal to be analyzed has been gated and impressed. The signal is analyzed through a Crown A-7 tape recorder driving the Quan-Tech analyzer in its auto-mode, and monitored by a Tektronix RM 35A oscilloscope. The Fairchild oscilloscope camera was used to take time exposures of the scope presentation.

Insufficient data has been obtained so far to generalize the results. It appears though, that no single preferable filter setting can be applicable to the whole area.

A study of unusual echoes in an abyssal depth north of Corsica, mentioned in previous reports (Hersey, 1965) was made during a fellowship study by Miss Atwater. The results point to the possibility that the diapiric structures observed are salt domes.

<u>Gravity Investigations</u> (Dr. Bowin, Mr. Nichols, Mr. Aldrich, and Mr. Ruppert)

The gravity characteristics of trenches and rifts of the world were studied during this reporting period. That the deep-sea trenches are not in local isostatic gravity equilibrium is obvious. Isostatic gravity anomalies of -100 to -200 mgal are the rule. However, the extent to which the trench areas of the world may be in regional adjustment is still to be decided. Since isostatic equilibrium takes place on a regional rather than a local basis, the mass deficit should probably be computed over an area including both the trench and the associated island arc (Talwani, 1964). The only area for which this appears to have been done is the Puerto Rico Trench where an over-all mass deficiency is obtained (Talwani, 1964, Figure 10). Integration of the gravity anomaly (using a planimeter) was performed on the gravity profile of the Aleutian Trench (Peter, Elvers, and Yellin, 1965, Figure 9) and on five gravity profiles of the Java Trench presented by Collette (1954, Figure 4-8). All the profiles yield positive integrated values using zero milligals as datum. However, using a +30 to +40 mgal regional datum for the Aleutian Trench, a negative integrated gravity anomaly value across the trench is obtained. Using a +20 mgal regional datum, as given in Collette's profiles, for the Java Trench profiles yields a negative integrated value for three of the profiles and positive integrated values for the remaining two.

It is important to ascertain whether all trench-island arc systems have an over-all average mass deficit, or whether some have an average mass excess. Clearly, if some have a total mass excess, then the convection hypothesis for their origin has major difficulties. In any event, knowledge of the total gravity field of trench-island arc systems is needed to study the total mass balance of these features, and thereby to interpret better their origin.

A summary of the gravity characteristics and dimensions of many rift and possible rift features of the world is presented in Table 1. All are characterized by negative free-air gravity anomalies although the values for the Red Sea do not depart greatly from zero milligals. The negative Bouguer anomalies suggest a mass deficiency beneath the Gulf of Aqaba and East African Rifts, whereas positive Bouguer anomalies and seismic refraction investigations show that there is dense material beneath the Red Sea, Gulf of California, and Cayman Trough. It is clear that as the width of the rift increases, the Bouguer anomalies become increasingly positive. The information collected in Table 1 suggests that about 40 to 100 km of extension of the earth's continental crust appear to be necessary before dense substratum begins to rise upward beneath the rift, and thereby change the gravity characteristics of the central trough.

From May 11 to September 4, 1965, the sea gravity meter was not aboard the R/V CHAIN. This period was used for testing and improving the operation of the meter. In particular, all the vacuum tubes were thoroughly tested and defective or marginal tubes replaced by well balanced tubes with low-noise characteristics. The JAN-type tube shields were replaced by heat dissipating tube shields. These and other adjustments of the gear train have resulted in marked improvement in operation over that obtained during the previous reporting period. Further, a new counter was installed to simplify and improve the entry of spring tension information into the shipboard computer.

<u>Magnetic Investigations</u> (Dr. Bowin and Mr. Aldrich)

Magnetic information, together with gravity, bathymetric, seismic and petrologic information, aids in the interpretation of the composition and history of the oceanic crust. The utilization of magnetic information usually requires the removal of a regional field and the determination of residuals. A study of possible methods for the determination of magnetic residuals has been our main activity during this report period. Analytical surface-fitting procedures are difficult to apply because our data are essentially continuous along the ship's track, but parallel track lines are commonly 30-60 nautical miles apart. Also, because of magnetic storms or diurnal variations, there may be differences in the measured total intensity of the magnetic field at crossings of the ship's track. The computer programs for surface fitting that we have investigated are not able to adequately process such discrepancies.

A solution appears to have been found by utilizing spherical harmonic analyses of the regional magnetic field, and this approach gives promise of being able to determine residual magnetic anomalies with the aid of the shipboard computer system while the ship is collecting the magnetic data in the course of the cruise. Once the coefficients have been obtained (Cain, et al., 1964) all that is required is the latitude, longitude, and date for which the regional field is desired. A computer program then computes

Table 1

Gravity Anomalies and Dimension of Rifts and Possible Rifts

	Maximum Free-Air Anomaly	Maximum Bouguer Anomaly Crustal Density=2.67	Width km
Gulf of Aqaba (Allan, Charnock, and Morelli, 1964, Figure 5)	-180	-100	26
East African Rift, Lake Albert (Bullard, 1936, p. 508)	-100	-190 (-50 to -80)	42
Red Sea, at 16°N latitude (Drake and Girdler, 1964)	0 to -40	+120	100
Gulf of California (Harrison and Spiess, 1961; Harrison and Mathur, 1964)	-70	+140	150
Cayman Trough (Data from R/V CHAIN Cruise 46)	-150	+330	220

the regional field at that position and time from the given coefficients. The program was originally given by Cain, et al. (1964) and subsequently modified by the Lamont Geological Observatory group. Lamont's program has been modified by us to accept the data in the format generated by the shipboard computer system. We are presently evaluating the results of a test of this method using data from CHAIN Cruise 46 in the area around Hispaniola in the Caribbean.

The trends of isoanomalic lines of large magnetic anomalies, discovered during a cruise of HMS OWEN in 1962 in the eastern Somali Basin, Indian Ocean, were investigated on Cruise 43 of R/V CHAIN in 1964. The method used to determine the local trend of the isoanomalic lines follows that described by Raff (1962). Forty-eight trends were determined and they have an average bearing of N 65° W. During this reporting period a compilation (in part supported by National Science Foundation Grant NSF GP-2370) of other magnetic investigations was prepared and analyzed. The compiled information (Figure 6) strongly suggests that a magnetic lineation trending between N 55° W and N 65° W exists between the Carlsberg Ridge and the Seychelles Bank over an area of at least 600,000 sq. km. The trends of the Carlsberg Ridge and of the Seychelles-Saya de Malha Ridge which border the lineated area are close to N 45° W according to the Physiographic Diagram of the Indian Ocean of Heezen and Tharp (1964).

Although similar, there does appear to be a distinct difference between the regional trends of the topography of the two bordering ridges and that of the magnetic anomalies. The significance of this difference in trend, if real, is unknown, as is the nature and origin of the source of the magnetic anomalies.

The discovery of a large area in the Western Indian Ocean having a magnetic lineation stirs hope that an important key to the structure and geologic history of this region has been found. It is important to ascertain what happens to this lineation to the east where the Carlsberg Ridge trends nearly due south. Does the magnetic lineament cross the ridge, disappear, change direction, or might it even be discovered on the opposite side of the ridge? To the west the lineament pattern may be helpful in determining displacement on the Owen fracture zone northwest of Seychelles Bank (Heezen and Tharp, 1964) and its possible continuation southward. The magnetic trends shown in Figure 6 suggest that the lineation may also occur on the western side of the Seychelles Bank and thereby furnish clues concerning the setting of this pre-Cambrian granitic platform.

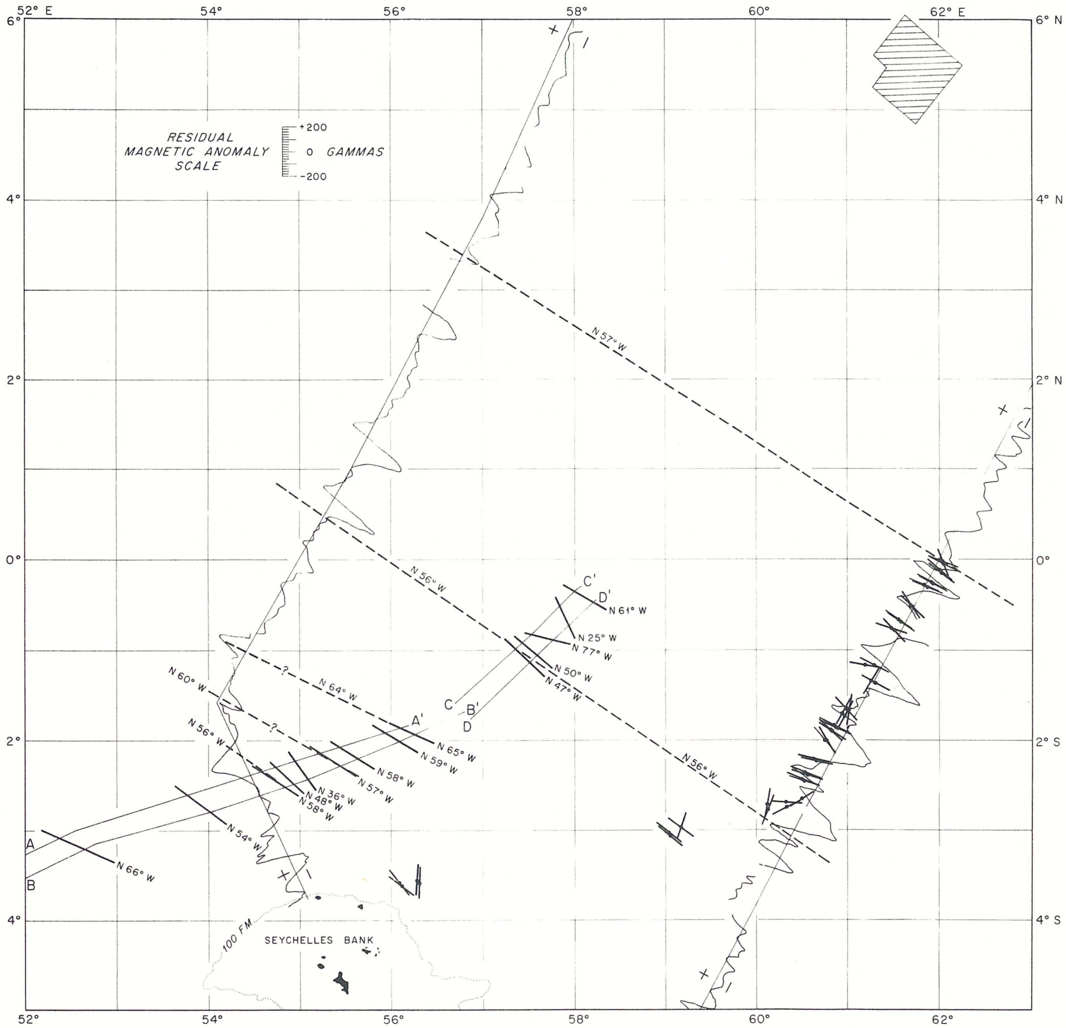


Figure 6. Magnetic lineations between Carlsberg Ridge and Seychelles Bank. The straight lines with dots at their centers were determined from jogs in the track of R/V CHAIN. The straight lines without central dots were determined from correlation of magnetic anomalies between profiles. The area investigated by Vine and Matthews (1963) and Matthews et al. (1965) on the crest of the Carlsberg Ridge is indicated by ruled lines.

Magnetic Analysis of Oceanic Rock Samples and Its Application to Magnetic Compass Variations in Submarines. (Dr. Phillips)

With the development of fluxgate and nuclear precession magnetometers, extensive magnetic surveys have been made over ocean areas. It has been generally assumed that the local magnetic anomalies found are attributable to changes of the induced magnetization of the geologic structures which reflects contrasts of the initial magnetic susceptibility and mineral composition. However, recent studies of the magnetic properties of oceanic rocks and the linearity of oceanic magnetic anomaly patterns have led some workers (Vine and Matthews, 1963) to propose that the observed anomalies at sea result from changes in the polarity of the remanent magnetization of the basaltic rocks of the ocean floor rather than susceptibility contrasts. In many basalts the remanent magnetization is hundreds of times stronger than that induced by the Earth's magnetic field, and nearly is equal to the Earth's field strength (Bullard and Mason, 1963; Nagata, 1961).

If current hypotheses proposing that the Earth's magnetic field direction has been periodically reversed in the past are valid (Irving, 1964), the remanent magnetization of some rocks may have been acquired in a magnetic field direction nearly opposite to the present field. Therefore, the local field direction especially near the ocean bottom, may deviate significantly from the normal field direction. Aboard submarines operating in such areas, reliance on magnetic compasses may be hazardous unless the magnetic effect of the rocks of the ocean floor is taken into account.

Preparations for a detailed study of the magnetic properties of oceanic rocks have been initiated. It is felt that magnetic analysis of dredged and cored rock samples with laboratory instruments, in conjunction with profiles of total magnetic intensity obtained with towed nuclear-precession magnetometers, will provide important information about the remanent magnetization of oceanic rocks. Such detailed knowledge will be useful both for evaluating the effect of remanent magnetization on the magnetic compasses of submarines and also in the geophysical interpretation of magnetic data obtained from such survey programs as "Project Magnet" of the United States Navy and the numerous shipboard operations conducted by various private oceanographic groups. With such data scientists may gain considerable insight in understanding such fundamental geophysical problems as the origin of the rocks of the ocean basins.

In order to measure the remanent magnetization of rock samples and test its stability a spinner magnetometer (sensitivity = 6×10^{-8} emu/cm^3) described by Phillips (1965) and an alternating magnetic field demagnetizer (maximum peak field 2000 oe) similar to that described by McElhinny and Gough (1963) have been designed. Construction is approximately 50% complete. The magnetic susceptibility of the rocks will be measured with a commercially available inductance bridge (Minnetech Laboratories, Model MS-I). Profiles of total magnetic intensity have been and will be obtained with the Varian Proton precession magnetometers of the R/V CHAIN and R/V ATLANTIS II.

Preliminary measurements of the remanent magnetization and susceptibility of rocks from the Mid-Atlantic Ridge have already been made using outside laboratory facilities. (Summary of Investigations, 1964, WHOI Ref. No. 65-13; Vogt, 1965). The results, indicating that the remanent magnetization is as much as 60 times the induced, tend to support Vine and Matthews' (1963) hypothesis that remanent magnetization is the major cause of oceanic magnetic anomalies. Other rocks available for study include basalts previously dredged from the Mid-Atlantic Ridge, Puerto Rico Trench, and the Barracuda Ridge near Antigua, B. W. I.

Frequency Distribution of Some Characteristics of Ocean Bottom Topography

(Mr. Mizula and Mr. Vine)

An analysis of the frequency distribution of bottom slopes, slope lengths, bottom curvatures and depths, determined from measurements on the echo-sounding records of two traverses across the central North Atlantic Ocean has continued. A quantitative estimate of the magnitude and the variability of the topographic properties has been obtained both for the transoceanic profiles and for profiles across many of the different types of topography found in the central North Atlantic. The quantitative data serve to augment qualitative topographic description and classification by allowing more precise definition of such concepts as "flat", "steep", "smooth", or "rough" topography, and by furnishing objective criteria to aid in defining and delineating different types of bottom topography.

A report on the findings of the study has largely been completed. One of the early findings was that bottom slopes, slope lengths, and bottom curvatures all appeared to be lognormally distributed. That is, the logarithms of the measurements, rather than the measurements themselves, tend to follow a normal distribution. Previous investigations of both submarine and terrestrial topography have variously reported topographic slopes to be normally and lognormally distributed (WHOI Ref. No. 65-13, pp. 140-142). It is primarily this aspect of the analysis that has received continued study during this period.

For a very few of the 90-odd sections which were analyzed, the dispersion of the data, the logarithmic standard deviations, were sufficiently low so that the data could about equally well be described by either a normal or lognormal distribution. (A lognormal frequency distribution plotted on an arithmetic scale shows a positive skewness which is a function of the logarithmic standard deviation. If this standard deviation is small, less than about 0. 14, the skewness is not pronounced and the distribution curve has nearly the symmetrical, bell-shaped appearance of a normal distribution regardless of whether an arithmetic or a logarithmic scale is used.)

In most cases, however, the distributions are clearly not normal, and although they are approximately lognormal, there are, for many of the profiles, varying degrees of departure from lognormality. There does not appear to be any recognizable pattern in the departures from lognormality that would suggest the use of different frequency functions for different types of ocean bottom.

It is felt that the observed departures from lognormality can be attributed to the presence in the profiles of more than a single type of topography. Analyses of slope, slope length, and bottom curvature are not all equally capable of detecting these topographic differences. Of the three, bottom curvature analysis appears most capable of detecting topographic differences that may be present in the profile sections. Analyses of slope length appear to be least sensitive to differences in topography.

One of the problems in a quantitative investigation of topographic characteristics is the choice of a sample for analysis. This was particularly difficult in the present analysis where two profiles across an entire ocean were to be divided into shorter sections so that data could be obtained about the characteristics of different types of ocean bottom.

Basically, this is a problem of topographic classification which has traditionally been qualitative in nature. The data here suggest that this problem can be fruitfully approached through, or guided by, the use of the statistical concept of a topographic population. A topographic population would represent a portion of ocean bottom topography, the surface of which was generated or formed by essentially similar geologic process under similar geologic conditions. If the profile section contains only one such portion of bottom topography, measurements of some topographic property, bottom slopes, for example, could be described by a single lognormal distribution. If different geologic processes or conditions have been in effect over different portions of the profile, the associated slope distribution would be the sum of two or more slope populations and would be expected to show departure from lognormality. The degree of departure being a function of the differences in the mean values and standard deviations of the component slope populations.

The frequency distribution curves of the topographic samples that show marked departure from lognormality also show, by the presence of two or more frequency maxima, indications that the distribution may be the sum of the distributions of two or more populations of the variable being analyzed, visual inspection of the sounding records in such cases generally confirms the presence of differences in the topography of the profile that had previously either been overlooked or had not been considered significant.

B. Techniques and Instrumentation

Introduction

The value and variety of studies to which acoustic measurements can be applied, be they echo-ranging, sound transmission, or continuous seismic reflection studies is directly related to the signal-to-noise ratio (S/N). An ideal situation, sought but not yet attained in our seismic reflection work, is one where the noise level is a uniform minimum across a broad frequency range from less than 20 cps to more than 5000 cps. In practice, there are, occasionally, minima of limited width in the spectrum of the noise where the level is lower than in other parts of the spectrum, tending to make the S/N high at these places. The problem is that the spectrum of reflected signals varies across the frequency range as a function of the structure and materials of the sea-floor and the strata underlying it; and the stronger reflected signals only occasionally coincide with the minima in noise.

The variation of reflected signal throughout the 20 cps to 5000 cps frequency range can be used as a valuable tool in the analysis of the nature of the sea-bottom. Of greater importance may be the application of such knowledge to sound transmission and other sonar problems. Yet, since it is clear that once we are committed to a certain technique for generating a sound signal, techniques to improve the S/N can only be applied to the received signal. Thus, at present, our effort is directed toward the development of less-noisy towed receiving arrays and the enhancement of the S/N of seismic data by various noise-reducing data-processing techniques.

Studies of possible improvement in signal-to-noise ratio by time and space-domain filtering, so called velocity filtering, with the added flexibility of adjusting delay networks by digital processing, are mentioned where we report the work done with Geoscience Incorporated. Some of the work on the receiving array is also reported later in this section. One aspect of the study of on-line signal processing techniques to be applied to seismic reflection signals has evaluated the application of averaging successive signals. The resulting maximum gain in S/N amounts theoretically to $\frac{n}{\sqrt{n}}$ where "n" is the number of samples averaged - much the same, as in receiving array theory.

<u>Averaging Wave Trains from Groups of Successive Seismic Reflections</u>

(Mr. Knott and Mr. Zarudzki)

We have devised a method for using the Computer of Average Transients (called the CAT by its makers, the MNEMOTRON Division of the Technical Measurement Corp.) whereby, on an alternating schedule, an average of a predetermined number of samples is computed, and then in the original time space, read out to recorders and other devices for display and analysis (Figure 7). Examples of tests recorded on the Precision Graphic Recorder, PGR, (Knott & Witzell, 1960), using this system, are compared with an optimum band-pass presentation in Figure 8. Although the averaged arrivals in the striped record may, at first glance seem difficult to correlate, the averaged information revealed deep reflections of the sparker signal which

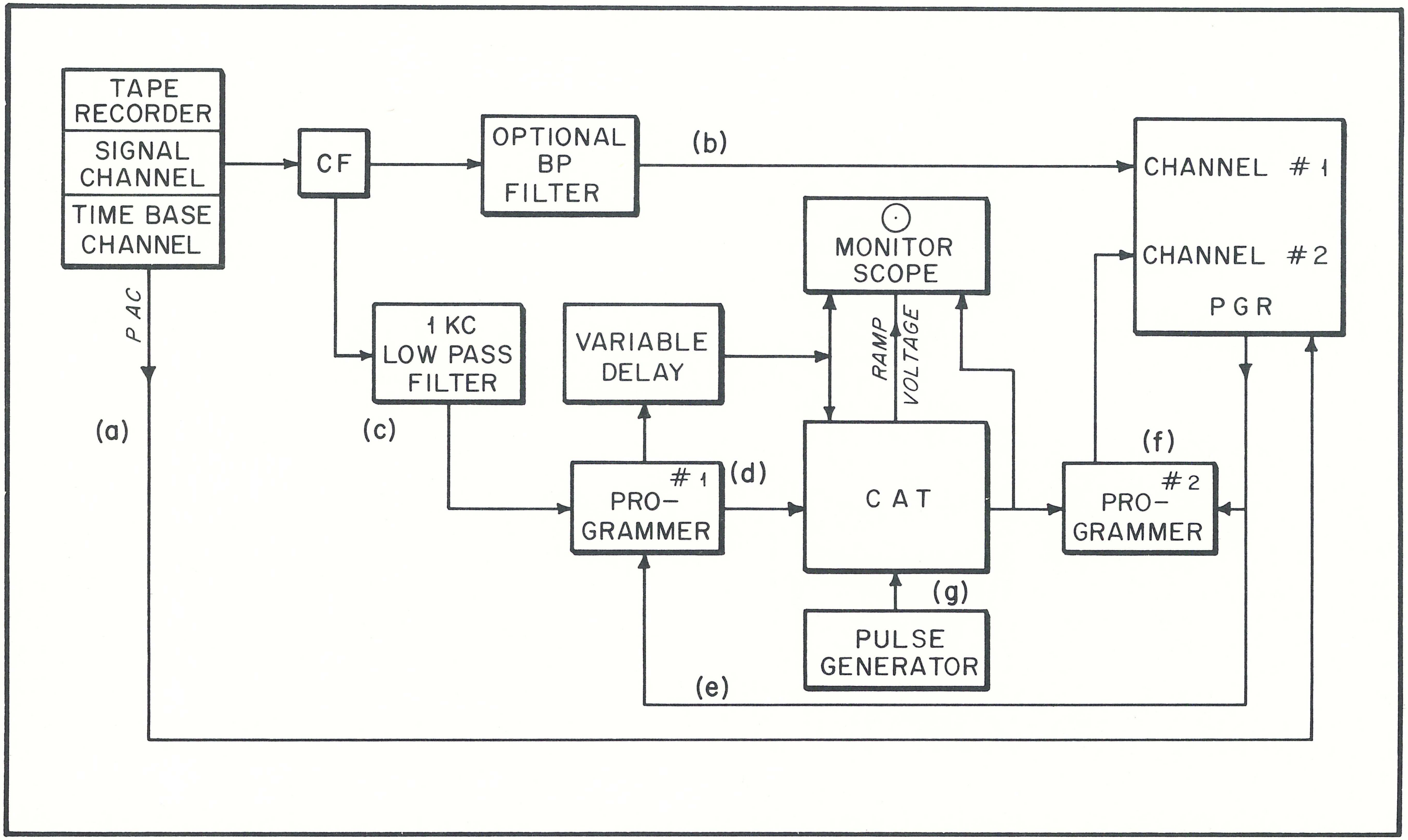


Figure 7. A system for using the Computer of Average Transients (CAT) in the analysis of seismic reflections.

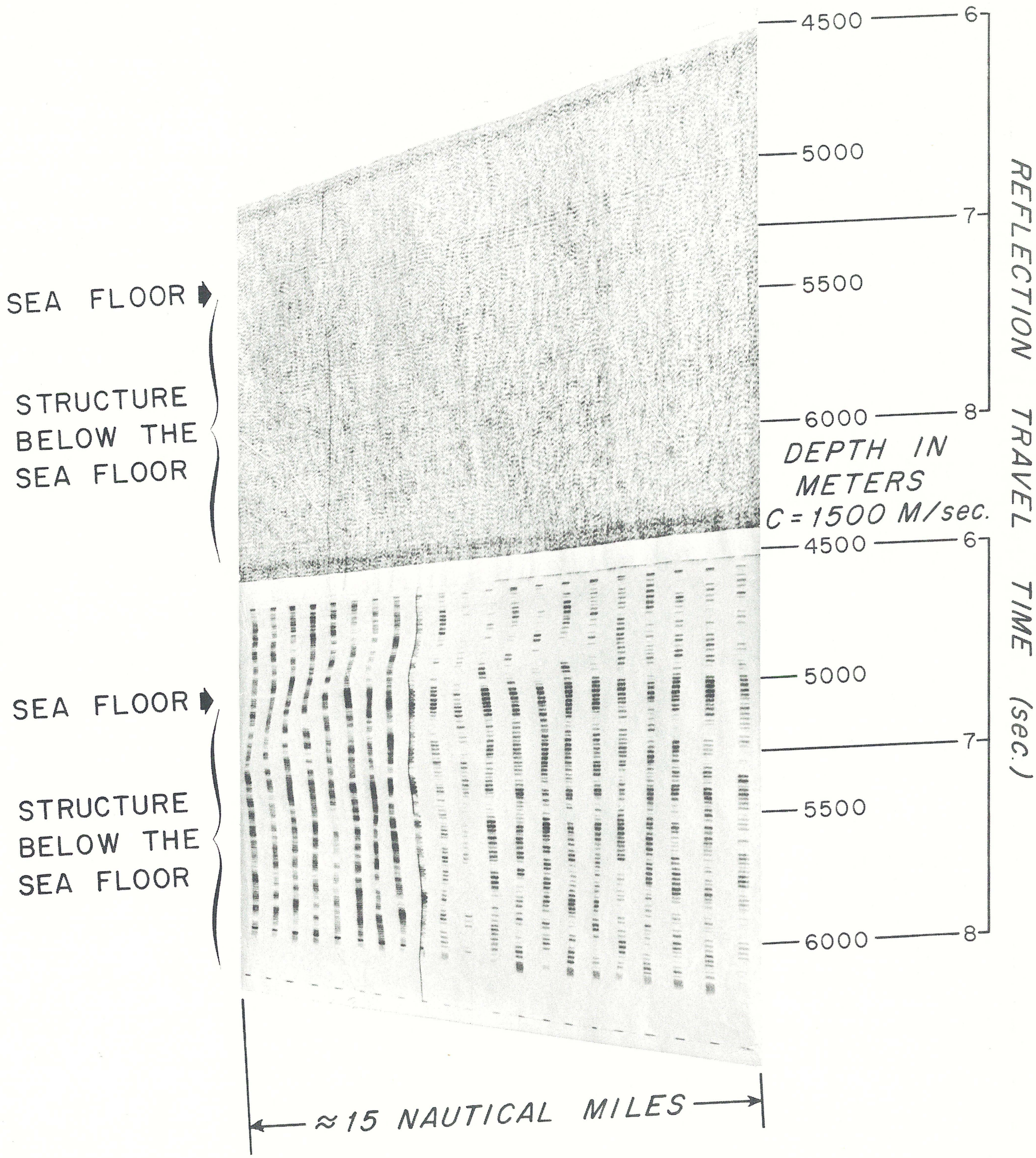


Figure 8. Example of seismic data processed in two ways: (Top) Through a band-pass filter; (Bottom) Through the CAT.

had not before been observable. Since the digital samples were taken 200 per second, the averaged data has in effect been passed through a 100-cps low-pass filter.

A similar but significantly different use of signal averaging equipment, provides a continuous, on-line statistical treatment which resembles a running average in which newest measurements are weighted more heavily than preceding ones. For this use we have applied units (Models ND-180F, ND-180M, ND-1801TB) made by Nuclear Data Inc. As compared to the configuration in Figure 7, this equipment requires only the addition of a signal gate to be put to use. A brief test-record of this system is shown in Figure 9 where unfiltered recordings are compared to data processed by this technique. In this example the weight given to the "averaged" data taken about ten sample periods earlier than that displayed was negligible. The digital sampling rate in the example was slow and, therefore, the processed data shows only low-frequency content, approximately below 50 cps. Here, a deep reflection, 2.0 seconds or more below the Hatteras Abyssal Plain, was revealed and then followed in a continuation of this test.

One of several possible applications of these on-line averaging techniques is to analyze the spectrum of the seismic reflections from the seafloor, after reducing the noise by averaging. Periodically the averaged waveforms can be read out to a wave analyzer, as well as to the PGR.

The application of either of the techniques offered by these devices suffers when signal arrivals change rapidly in range or travel time. Since changes in subbottom structure can be made to appear very gradual by moving the ship very slowly over areas of interest, these averaging (or "signal stacking") techniques can be applied to many studies.

It is interesting to note that an averaging technique is also useful although the noise may not be truly random. In seismic reflection work, as in echo ranging, signals or reflections are expected to arrive with definite relationships to the time base and repetition rate at which samples are taken. Although the noise within itself may be correlated, such as noise from sixty-cycle electro-magnetic pick-up and ship's screw beats, it does not necessarily correlate from sample to sample in the precise time space generated for the repetitive seismic reflection measurements. Some gain in S/N is therefore generally realized by averaging in these cases.

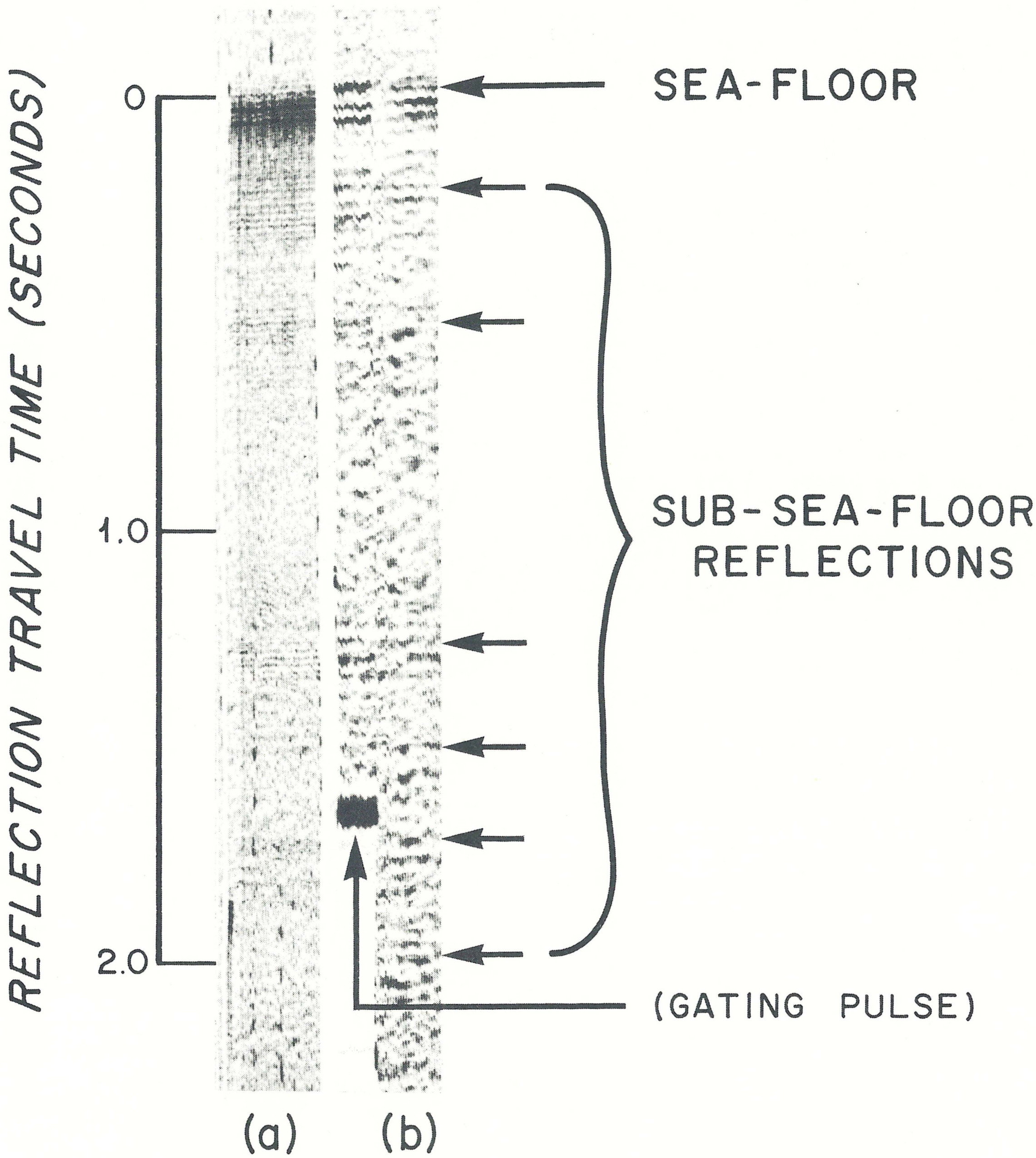


Figure 9. (a) Seismic reflections recorded through a 20-cps to 300-cps band.
(b) Continuous readout of data processed by Nuclear Data equipment (see text) before recording.

Application of Linear Filter Theory to Towed Hydrophone Arrays (Dr. Beckerle)

Under contract to WHOI, Geoscience Incorporated has been studying the application of digital data analysis techniques to towed hydrophone array signals. The effort during the past period has consisted of the following:

1) Data acquisition: A Geoscience Inc. scientist participated in one leg of CHAIN Cruise #51. During the cruise a carefully controlled flow-noise experiment was performed using the sectional hydrophone array. In addition, bottom and subbottom profiling runs were made using the sparker source. Good quality records of both flow noise and sparker returns were obtained on magnetic tape for later processing.

2) Data Processing: Power spectra and multi-hydrophone coherencies were computed using the flow-noise data obtained on CHAIN #51. Data had been obtained at speeds of from 0 to 12 knots in 2-knot steps. These calculations indicate that the noise power-spectrum is dominated by a large peak at low frequencies below 100 cps and that the peak moves up in frequency and broadens as ship speed increases. The low frequency noise is found to be incoherent at all speeds and the higher frequency noise (100 - 500 cps) becomes more incoherent as ship speed increases. These results are being studied in detail and will be presented in a formal technical report.

Sectional Hydrophone Array (Mr. Dow, Mr. Grant, and Mr. Scott)

The sectional hydrophone array described in the previous progress report (WHOI Reference No. 65-46, p. 34-35) has been employed for seismic profiling on cruises during this period and has proved quite rugged and capable of withstanding severe shock and strain. Design of the hydrophone elements has been improved and the new units installed. It is believed that performance, particularly above 6 knots, could be considerably improved by altering certain towing characteristics of the array and decreasing the drag of the tow cable. The revisions are now underway. Installation of a vibration damping section to isolate tow-cable vibration from the hydrophone elements is also contemplated.

Reconstruction of Chesapeake-type Array (Mr. Nowak and Mr. Knott)

Since we have accumulated much of our experience with towed hydrophone arrays using Chesapeake Instrument types, one such array is being maintained for field use and as a base for evaluating the performance of different experimental array designs. To this end, the better components from our old Chesapeake-type arrays were recently re-built for use on Cruise 53 of CHAIN. A number of modifications to the basic Chesapeake design were made to try to eliminate some of the difficulties encountered in the earlier Chesapeake models. The array consists of five Chesapeake PC100 transducers spaced at intervals of twelve feet in an oil-filled, thin-wall, neoprene hose. Departures from earlier design consist of using a ten-foot section of oil-filled hose between the first hydrophone and the preamplifier housing, and using oil-tight bulkheads with individual filler holes between each hydrophone. Although other arrangements can be used, a single preamplifier is presently proceeded by a step switch which provides a means for remotely selecting on shipboard individual hydrophones or all hydrophones connected together in parallel. Pinger units to determine tow depth by echo sounding to the surface are placed halfway between each receiving hydrophone. Only one pinger and its adjacent hydrophone can be selected at a time. Two types of pinger transducers were installed, the Chesapeake PC100 transducer which has a resonant frequency of about 5 kcps, and a ceramic cylinder transducer which is resonant at about 20 kcps. The higher frequency unit provides a higher degree of resolution for the echo sounding measurements, but signal levels are not as high as those obtained by the use of the lower frequency pingers. In addition, two pressure-sensing potentiometers are placed, one at each end of the array, to provide additional and possibly continuous depth information. The use of the pressure sensors in this application has not yet been completely evaluated.

Acoustical Absorption (Mr. Bennett)

The fact that large errors attend measurements of acoustic absorption in sediment specimens which have been even slightly disturbed by sampling is now generally recognized. A program for the development of in situ measurements of absorption in sediments has been supported by this contract. These measurements are being pursued through three approaches over the frequency range of 40 to 600 cps and also at 12 kcps. The data being used include continuous seismic refraction profiles obtained for this purpose, and continuous reflection profile and echo-sounding data collected previously for other purposes, but available and useful to this study.

A previously described technique (WHOI Reference No. 64-50) using the attenuation of critically refracted rays (head waves) from repeating pulse sources has given results in the range of 4×10^{-3} to 8×10^{-2} db/m for the lower frequencies (75 - 225 cps), but these results contain large uncertainties (0. 1 db/m). Further correction and refining of the data will change these values somewhat. The practical difficulties with this method include: a lengthy analysis of the data is required to observe the low-level signals which vanish into the noise as range increases; and, the areas where measurements are to be carried out need to have a simple geological geometry.

The remaining two approaches to attenuation measurements _in situ_ are complementary to each other although applicable in different frequency ranges. The first of these uses oscilloscope photographs of short-pulse, 12-kc echo-sounding reflections in areas where the echo-sounding record indicates several shallow subbottom reflectors. The assumption here is that two or more of the stronger subbottom reflectors have similar reflectivity, an assumption which appears justified in at least some areas of deep-sea turbidite deposition. The decrease in echo strength of the stronger subbottom reflectors with travel time beyond the bottom reflection, after estimating the effects of proceeding reflections, indicates an additional loss, frequently in the order of 0. 1 to 0. 3 db/m. This is lower but within an order of magnitude of the absorption expected by Wood and Weston or Shumway at 12 kcps. While no nearby core has yet been measured to correlate with these data, there seems reason to expect that there are large areas in the ocean where this method can yield information on _in situ_ absorption at echo-sounding frequencies for relatively little additional effort.

The other approach being pursued is through the study of tape-recorded continuous seismic-reflection profiler data from an area where a single, strong reflector dips slowly beneath a flat bottom. On the reasonable assumption that both the bottom and subbottom reflectivity remain constant over a few miles, the change in the ratio of the energies in the two reflections is a measure of the absorption. The broad spectrum of the continuous seismic- profiler sources (Sparker in this case) permits this to be studied over a range of frequencies from 40 to 600 cps and higher. At the present time, an evaluation of this technique seems to be qualitatively satisfactory. Work on each of these phases has recently been accelerated by the acquisition of a modern oscillogram reader.

Automatic Depth Determination (Mr. Hess)

The Automatic Depth Determination System described in the last Progress Report has since been used operationally aboard the Research Vessel CHAIN. This system provides automatic echo-sounding depth measurements in digital form to the shipboard computer system.

To review; the system, shown in Figure 10, which incorporates its own echo-sounding receiver-transmitter, measures the time interval between the transmitted ping and the received echo. Midwater targets, which would cause false depth indications (since they would arrive earlier than the bottom echo), are eliminated by use of an automatic range-gate system. The range gate "remembers" the travel time of the bottom echo from the proceeding ping and will not accept an echo which differs from this by more than 0. 2 seconds.

Visual display is by means of lighted columnar digital display in fathoms and tenths of fathoms. In addition, a 5-digit, parallel, binary-coded, decimal (BCD) electrical output, which is compatible with the IBM 1620 computer, is provided. An "interrupt program" contact-closure is provided to signal the computer that a valid depth measurement has been made. Inability of the computer for any reason to accept the depth measurement immediately is overcome by the provision of a memory shift register in the Automatic Depth System so that the computer can read the number at its convenience.

The use of this system has reduced the top-laboratory watch requirements. The manual entry of depth to the computer by an operator required continuous attention. This watch stander is now free to perform different assignments. The Automatic Depth Determination (ADD) system requires only occasional attention to check its accuracy when bottom topography is relatively uniform.

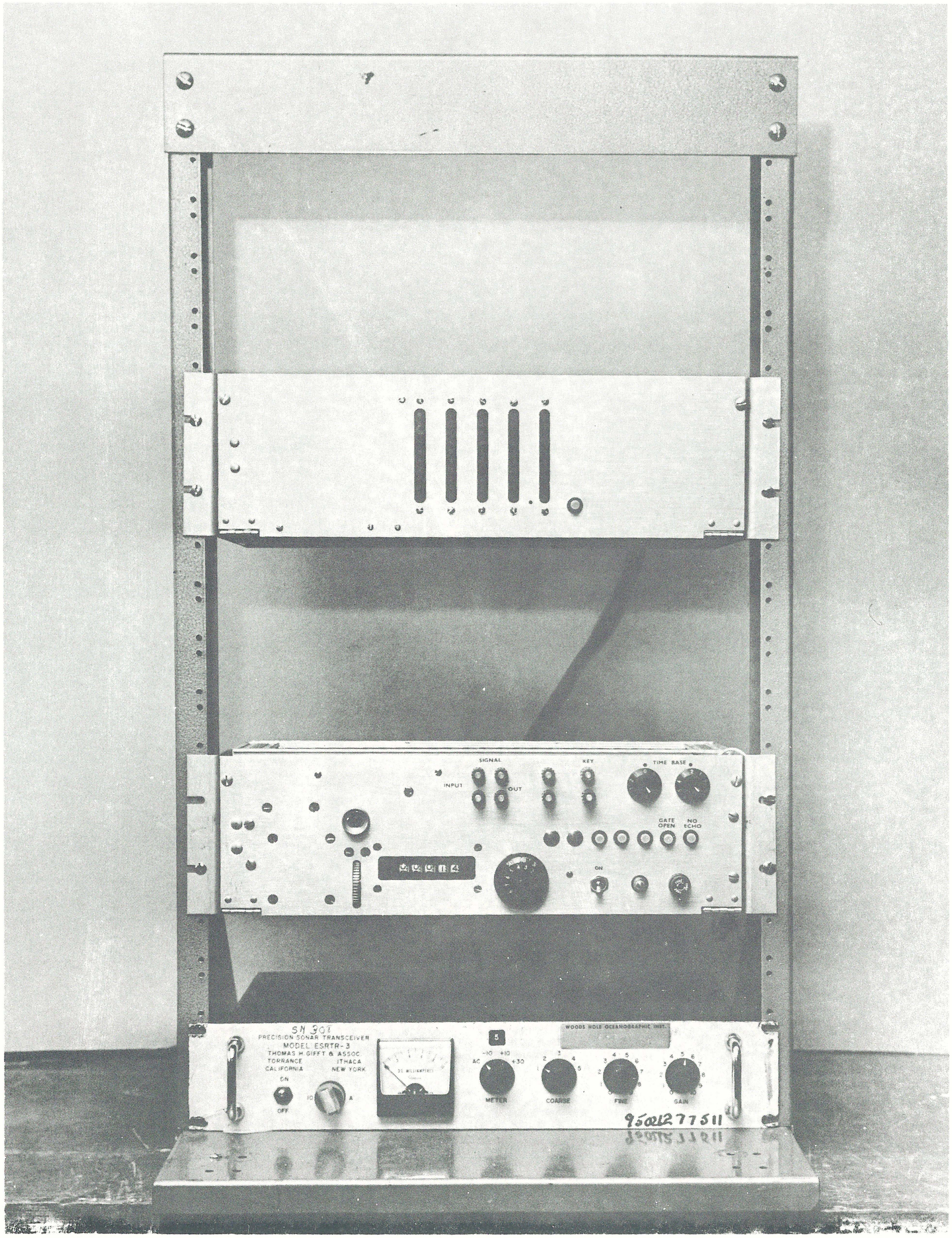


Figure 10. Automatic Depth-Measuring Equipment.

A wide dynamic range preamplifier for radio-linked hydrophone receivers
(Mr. Hess and Mr. Knott)

A hydrophone preamplifier which was used successfully in deep-water seismic-reflection work during Cruise 53 of CHAIN was designed to have a dynamic range of 56 db for any given attenuator setting and flat response from less than 20 cps to 50 kcps. Tubes rather than transistors were used to produce an amplifier whose signal voltage swing was more nearly equivalent to those anticipated from the hydrophone, and remotely controlled signal attenuation was incorporated. The hydrophone element is the Brush AX-120 which has been in use for many years. In addition, a calibrating square wave of very high purity and known amplitude is incorporated for standardization of the system.

Control of the attenuator from the surface buoy allowed the system to be set for optimum gain for different ranges and sea conditions without retrieving the hydrophone from 1000 feet below the attendant radio buoy. The overall gain of the amplifier is adjustable by means of the attenuator in 6 db steps from 20 db to 80 db. Equivalent input noise is 3 microvolts RMS.

The entire unit is contained in a 2"-diameter, twelve-inch long pressure case. This required a 6-inch extension of the standard AX-120 hydrophone case but caused no difficulties.

C. Reports and Routine Data Processing of Shipboard Observations

Cruise Navigation and Bathymetry Reports, and Charts (Mr. Dunkle, Mrs. Witzell, Miss Hays and Dr. Hersey)

Two cruise navigation and bathymetry reports were completed during this period:

WHOI Reference No. 65-15 ATLANTIS, Cruise #260
WHOI Reference No. 65-14 ATLANTIS, Cruise #282

This type of report summarizes the location of the various observations made during the particular cruise, and contains the ship's track plotted on a scale of 4 inches per 1° of longitude, and bathymetry along the ship's track.

Compilation of Geophysical and Geological Data (Mr. Dunkle, Mrs. Gallagher, Mr. K. Fuglister)

The locations of the various observations made on cruises mounted in the last ten years by the Department of Geophysics and other groups at Woods Hole continue to be compiled on a series of charts having a scale of 3/4 inch per 1° longitude. The coverage of the WHOI Plotting Sheet Series used for these compilations is shown in Figure 11. The compilation of bathymetric observations (a continuous observation on most cruises) now includes the coverage of 39 cruises, 34 having been added during this reporting period. Compilations of the locations of continuous magnetic field intensity measurements, underwater photography (usually bottom photographs), and sound-velocity stations have been completed. Compilations of gravity measurements and continuous seismic reflection profiles are well underway.

In our continuing program in bottom photography there are now on file 26,730 stereo-paired and 17,085 single prints of bottom photographs. The locations of these observations are compiled on the previously mentioned plotting sheet series. Location information and other pertinent data are also listed with the filed prints.

Each camera lowering generally contributes several hundred prints making up a photomontage of considerable coverage of the bottom which is particularly useful in evaluating the roughness of the bottom.

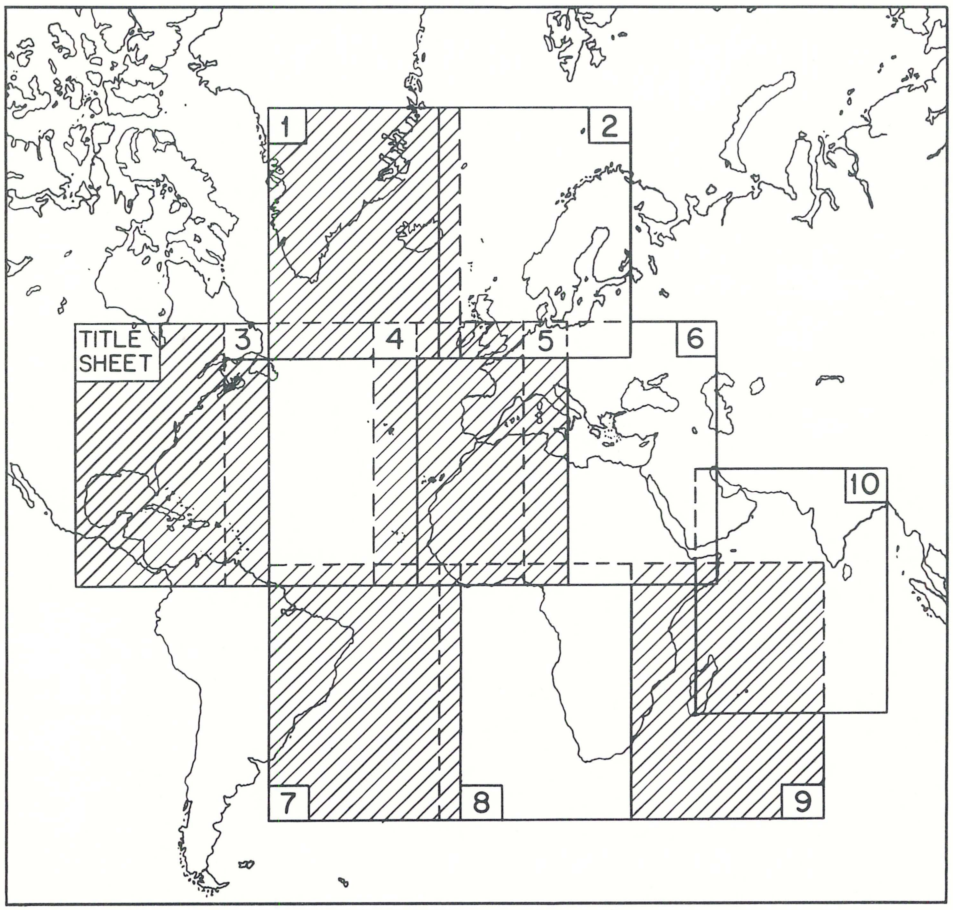
A film library of 35-millimeter copies of the majority of all records of continuous observations is being maintained. The file includes copies of the following original records on hand: bathymetric records; echo-location records of camera, sound velocimeter, dredge, corer and such lowerings; continuous seismic profiles; and continuous summary plots showing simultaneous measurements of magnetics, gravity and bathymetry.

W. H. O. I.

PLOTTING SHEET SERIES

MERCATOR PROJECTION

1° LONGITUDE = 0.75 INCHES — SCALE 1:5,845,000



NOTE:

THE DEPARTMENT OF GEOPHYSICS CHOSE THIS SERIES OF PLOTTING SHEETS TO PROVIDE A UNIFORM BASE FOR THE PLOTTING OF SCIENTIFIC DATA. THE OUTLINE CHART SHOWN INCLUDES ALL SHEETS THAT HAVE BEEN PREPARED. EACH CHART MAY BE ATTACHED TO IT'S ADJOINING SHEET OR MAY BE CONNECTED TO FORM ONE LARGE MAP. NAMES OF COUNTRIES, ISLANDS, AND PORTS HAVE BEEN OMITTED BUT CAN BE ADDED WHEN NEEDED. PLOTTING SHEET CONTROL TAKEN FROM H.O. OPERATIONS CENTER PLOTTING / DISPLAY CHARTS 17,000 (.75") SERIES.

THESE CHARTS WERF PREPARED BY THE CHART AND MAP REFERENCE LIBRARY OF THE WOODS HOLE OCEANOGRAPHIC INSTITUTION.

THIS WORK WAS PERFORMED UNDER CONTRACT NONR-4029(00) WITH THE OFFICE OF NAVAL RESEARCH.

Figure 11. WHOI Plotting Sheet Series.

HYDROACOUSTICS

A. Investigation and Analysis

Distribution of sound-scatterers in the Western Sargasso Sea (Dr. Backus)

In its western part, the Sargasso Sea runs from the Gulf Stream in the north to the Bahamas and Greater Antilles in the south. It is common to think of the ocean as being rather homogeneous over this stretch, but there is a good deal of evidence that this is not so. Attention has recently been called to the existence of so-called "thermal fronts" in the southwestern Sargasso Sea (Voorhis and Hersey, 1964). These relatively superficial features run roughly east-west, show a sudden temperature drop across them to the south, are best developed in the winter, and are most commonly encountered near 28° or 29°N. Their existence implies that the ocean region north of them is different from that to the south.

One goal of CHAIN Cruise 49 (June 1965) was to see if the region of the thermal fronts has any significance as a boundary between ocean regions having different midwater faunas. To this end, 22 collections of mid-water animals were made with a 10-foot Isaacs-Kidd midwater trawl along 70°W from Silver Bank Passage (21°N) to about 38°N at the Gulf Stream. Accompanying these collections were observations of midwater sound-scattering at 12 kcps, using a UQN-1b and PGR, it being our hypothesis that changes in the composition of the midwater fauna are accompanied by changes in sound-scattering. Although thermal fronts were expected to be poorly developed in June, we sought them by making surface temperature observations using a recording thermistor and hourly bathythermograph observations.

The 12-kcps echo soundings made during CHAIN 49 on June 17-20 show that there is a very poor development of deep scattering layers in the southern part of this area. With the echo-sounding system pushed right to the limit of noise, we saw a fair amount of patchy scattering in the upper 100 fathoms with almost nothing deeper save for a faint layer occasionally appearing at 300 fathoms.

A marked change in the sound-scattering picture took place during the early hours of June 21, and deep scattering layers were quite well-developed in the area thereafter. Generally, two pronounced layers were detectable, one with its top near 200 fathoms and another with its top near 250 fathoms. At times, these two formed a continuous band of reverberation between 200 and 300 fathoms.

Coincident with the change in sound-scattering, a change in facies of the ocean in general was noted. In keeping with the increase in sound scattering, there was an increase in other signs of life, and the ship seemed to be passing out of the trade winds region with its typical weather.

These changes occurred between 28° and 29°N and were accompanied by a marked and sudden change in the temperature structure of the water column as shown by the hourly bathythermograms. This change consisted of a surfacewards migration of isotherms, such that the 20°C isotherm moved from 200 m or below to 100 m or above. This is interpreted as a manifestation of the front phenomenon already mentioned, although surface temperatures showed no sudden cooling, but rather a slow, steady cooling. As noted above, surface manifestations of these fronts are expected to be slight during the summer.

The twenty-two collections of mid-water animals made between Silver Bank Passage and the Gulf Stream have been studied little so far, but the displacement volumes of the fishes caught have been measured. Collections 1111-1123 were made over the track of weak sound scattering south of the thermal front, and collections 1124-1132 to the north of there. The mean volume of the first group is 9. 15 units, that of the second, 35. 14.

We argue simply, until more information disproves it, that the western Sargasso Sea can be divided into two areas by a zone of thermal fronts near 28° or 29°N. Populations of mid-water animals and volume reverberation levels are higher north of this front than they are south of it. The same can be assumed to be so of the incidence of false targets.

The zone of the thermal fronts itself can be expected often to be the site of unusual biological activity as are almost all zones where differently characterized areas meet.

<u>Ambient Noise</u> (Mr. Schevill and Mr. Watkins)

Analysis of a wide variety of underwater sounds has been the main interest this period. These include the sounds of antarctic and arctic ice that covers the entire spectrum with all kinds of squeaks and trills and groans, the walrus and its bell-like calls, two kinds of antarctic seals with their musical calls, the killer whale's loud-strident voice, the narwhal's distant talk, and the porpoise with its rapid modulated click series. This work has been done jointly with Contract Nonr-4446. Further study of 20-cycle signals is also in hand.

In May, with the cooperation of ONR (446), NAS Quonset, and the Coast Guard, we spent some time off shore between Cape Cod and Sable Island on the movement and distribution of the whales that contribute to low-frequency ambient. Efforts were concentrated especially on the right whale and their migration past Cape Cod. This included photography, visual reconnaissance, and radio tagging.

In October we engaged in a joint operation with NEL off Point Sur, California, using USS SALUDA (IX 87) and S2F airplanes out of NALF, Monterey. The weather was very unfavorable, and though results were generally negative, some recordings (including Dall's porpoise) and cetacean contacts were made.

Mr. Schevill attended the Inter-American Naval Research Conference in Puerto Rico in July.

<u>Sound-transmission in the Convergence Zone of the Mediterranean Sea</u>
(Mr. Baxter, Mr. Brockhurst and Dr. Hays)

During long-range transmission experiments south of Cyprus in November 1961, we noted that low-intensity refracted arrivals were received at shorter ranges and travel times than predicted by ray acoustics from any possible average-sound-velocity profile. The increase in broadband acoustic intensity as the source increased range toward the convergence zone and entered it was much more gradual than that predicted by ray theory, and the first maximum of the broadband acoustic intensity was received at a range about a mile greater than predicted.

Considering the high near-surface gradients indicated by thermistor tows during and after the experiment, these results are more easily explained by diffraction than by scattering. Assuming diffraction, high frequency components of a Fourier analysis of the data should yield intensity measurements closer to ray theory and indicate the precise location of the convergence zone, while lower frequency components should map the diffraction effects. Such a detailed empirical study of diffraction effects on convergence zone transmission is valuable because theoretical computation is very difficult even for relatively simple models.

During the period 1 May - 31 October, extensive digital analysis has located the precise convergence zone (consistent in the 800-cps component with ray theory), and mapped the acoustic intensity as a function of range for components at 800, 667, 533, 400, 267, 133, and zero cps. (The zero-cps component is, of course, really representative of energy at frequencies lower than the fundamental of the analysis period.)

Since the analysis was based on arrival times taken from the broad-band flow-plots discussed in our previous progress report (WHOI Reference No. 65-46, p. 35-36) and since arrival times for the 133 and zero-cps components appear to vary more than expected, the intensity-versus-range for the last two components may be less accurate than desired.

Our results show significant effects consistently increasing with decreasing frequency (as would be the case for diffraction on all components below 800 cps). We are preparing these results for journal publication.

<u>Bottom Reverberation</u> (Mr. Hall and Dr. Hersey)

During this report period, an analysis of bottom reverberation was concluded. A total of thirty-eight explosive shots from eleven locations in the North Atlantic Ocean and Eastern Mediterranean Sea were digitized at 51 time points between the first and second bottom reflections for twenty logit frequency bands between 100 and 10,000 cps. Backscattering coefficients were digitally computed for all 1020 time-frequency points using a model similar to that developed by Chapman and Harris (1962) for surface reverberation investigations. The data was examined statistically for repeatability of shots from the same location, and for variability between locations. Noise corrections were finally made when increased programming skills allowed manipulation of incomplete data arrays. All results were then recomputed, and the final data limited to nine shots from seven locations. A good physiographic selection is offered by these locations. The final results were automatically plotted, and fit to a variety of curves suggested by radar and acoustic scatter theory.

At present the bottom-reverberation process appears to result from specular reflection for grazing angles of 90° to 70°, and backscattering below 70°. A complete report is in preparation.

B. Instrumentation and Techniques

Acoustic Measurement of the Motion of Sea Spider (Dr. Hersey)

As outlined elsewhere, a main design objective of Sea Spider was to maintain the structure as nearly fixed as possible with respect to the earth, both in translation and rotation. The plan for measuring its motion was to monitor over a period of days the acoustic travel time between two sources about two miles apart on either side of the central float and an array of four receivers on Sea Spider. The receivers were attached at the float and about 800 feet down from the float on each of the three mooring lines. These hydrophones were operational through the early weeks of the work at sea, but their telemetering radios caused major delays and the sound sources proved not to be loud enough to be detected at a mile over an unexpectedly high background noise at the receivers in tests early in August.

During these early tests the sound source, a 4-kc pinger, was pulsed once every thirty seconds, an interval for which our recording apparatus provided no processing gain. A high signal-to-noise ratio had been anticipated. After the sound sources proved too weak for the prevailing conditions, the programmer of one was altered to pulse once per second. The second unit had flooded and was beyond repair. The remaining operational unit, however, could be heard by ear out to a distance of 0.6 miles from Sea Spider's float when towed at shallow depth. It was then lowered to the bottom at about this distance. In this position it could no longer be heard, but, when recorded on the Precision Graphic Recorder (PGR), operating on its one-second sweep, visual correlation allowed the received pulse train to be discerned quite readily.

By this time (late August) the receiving equipment had been reduced (because of cable failure at a connection to the telemetering radio raft) to a single jury-rigged hydrophone on the main float. Travel time of the sound pulse from the single source on bottom to the single receiver at the float was monitored on one to three PGR's for nearly thirty-six hours. The quality of the records vary, but there were long periods of acceptable recording during which the arrival times of the pulses could be compared with the sweep rate of two of the PGR's. The time signal from radio station WWV was recorded for many hours on one of these PGR's. From these measurements it proved possible to detect travel time variations of about 0.5×10^{-3} sec (2.5 feet travel), but it was possible only to determine that such variations were not in the manner of recording or comparing with WWV on the ship. The pattern of arrivals showed a very small steady drift which was attributed to the crystal oscillator controlling the source. Superimposed on this steady drift were long-period oscillations (ca. 14 to 22 hours) having a maximum (peak-to-peak) excursion of 4.0×10^{-3} sec. Short period (an hour or less) oscillations were clearly less than 0.5-0.6×10^{-3} sec. At this writing it is not possible to translate these observations into motion of Sea Spider. It seems possible that oscillatory translations having an amplitude of ten feet about a mean position may have occurred. It seems equally possible that the observed variation in arrival time was caused by mechanical drift in the programmer of the sound source.

The design objective of Sea Spider (maximum translational motion of 3-5 feet) may have been achieved or it may have been narrowly missed. In any event the performance of the structure seems quite promising enough to be well worth further development of the concept and the hardware as an oceanographic and acoustic tool having great potential.

<u>Acoustic Navigation through Accurate Measurement of Ranges</u> (Mr. Olmsted and Dr. Beckerle)

In anticipation of experimental possibilities with Sea Spider, a method for short-range (5 km), high-accuracy acoustic navigation has been derived and implemented.

The method requires a pair of hydrophones rigidly fixed at some convenient depth and with a horizontal separation on the order of several hundred meters. If we can measure the distance of a ship from these two points with sufficient accuracy (within 5 meters), then the position of the ship relative to a fixed point (say one of the hydrophones) can be determined by triangulation with the same accuracy in range and with an accuracy of well under a degree in bearing.

In order to obtain this high accuracy in the measurement of range we must take account of the variation with depth of the speed of sound in the water. Computer programs have been written (in FORTRAN language) which, utilizing acoustic ray theory, solve for the range given the travel time and a sound-velocity profile.

The results are presented in a tabular form compatible with shipboard travel-time measuring instruments such as the PGR or PDR so that quick and easy at-sea reduction can be made of acoustic fixes.

These tables are general enough so that they can also be used in any experiment such as oblique seismic profiling which requires accurate measurement of range.

The first use of these tables occurred during experiments with and around the Sea Spider.

GENERAL INSTRUMENTATION

Project Sea Spider (Mr. Savage)

The purpose of project Sea Spider was to design, build and test a near-motionless buoyant structure that would extend from the deep ocean bottom to within 100 feet of the surface. The project began in March 1964. Mathematical design of the structure and computer analysis of the motion was completed in October 1964. Since that time the first Sea Spider prototype was constructed and field tested on the Blake Plateau. This hydrostructure had been proposed and designed to serve as a navigational reference frame for precise (±200 ft.), local (within a radius of perhaps 20 miles from the structure) navigation in the deep ocean, and as a near-motionless instrument base from which to measure acoustic, current, temperature and other phenomena that have proved highly sensitive to extraneous instrument motions introduced by ship motions or buoy excursions and vibrations.

Last winter and spring were devoted to turning this engineering conception into operational blueprints and then into component parts for the structure. At the same time, our scientific and technical staff designed several special experiments to be undertaken using Sea Spider and built the hydrophones, thermistors, radio telemetry, bottom-mounted sound-sources, and other equipment to accomplish them. The task of collecting the some 50 major components of the main structure and its hundreds of associated small parts plus all of its instrumentation was a major logistical undertaking for WHOI. The R/V CHAIN had to be specially rigged to serve as the installation ship for the 25-ton structure. CHAIN, under Miss Elizabeth Bunce, made a survey of the proposed site (29°N, 78°W) in April to determine bottom topography and bottom composition. GOSNOLD (Cruise 73), with Albert Erickson as chief scientist, sailed twelve days ahead of CHAIN (Cruise 51) to study further the installation site on the Blake Plateau, measuring currents, depth, dredging the bottom, and tracing out acoustic patterns surrounding the site so that subsequent Spider seismic work could be tied in with prior surveys in adjacent areas.

CHAIN 51 was divided by plan into four subcruises of nearly equal length:

Leg 1 - Installation of Sea Spider and its instrumentation. Engineering tests to determine the structure's resistance to wave and current surges and check out of instrumentation.
Chief scientist: G. H. Savage

Leg 2 - Acoustic navigation experiments using Spider hydrophones for reference, temperature and sound velocity experiments to study internal waves, reflection seismology.
Chief scientist: Dr. J. Beckerle

Leg 3 - Acoustic measurements of motion of Sea Spider; investigation of bottom reflectivity changes using acoustic navigation from Spider and coordinated with dredge hauls, cores and bottom photography. Chief scientist: Dr. J. B. Hersey

Leg 4 - Retrieval of structure and instruments plus several continuous seismic profile runs to tie in CHAIN Cruise 51 work with previous work in adjacent areas. Chief scientist: E. F. K. Zarudzki

Personnel changes were accomplished by bringing CHAIN to Charleston, South Carolina, approximately 160 miles from the site. CHAIN departed Woods Hole on July 22 and after several delays due to difficulties with the Spider's radio telemetry system and weather, succeeded in installing the structure as planned by August 4. Figure 12 is a sketch of Sea Spider. The three main cable legs were rendered neutrally buoyant by 75 equally-spaced, 10-inch diameter glass spheres attached along each leg. Thermistors and hydrophones were placed on each leg, 950 feet below the surface; a string of four self-recording Richardson current meters were suspended on a vertical wire extending from the sub-surface float (a 9-foot diam., aluminum ellipsoid) to the sea floor. The Radio Buoy was connected to the sub-surface float by an elastic-electrical connector through swivels with 22 separate conductors to transmit information up to the radio.

Due to difficulty with the radio telemetry, which was a most ambitious and necessarily advanced 2-channel, suppressed carrier system, some of the scientific studies planned for the cruise had to be curtailed or redesigned at sea. A review of the objectives vs accomplishments is as follows:

1) <u>Installation feasibility</u> - complete installation as per design accomplished in 37 working hours vs 48 planned - highly successful. This was accomplished by CHAIN using inflated 14-foot Zodiac boats with GOSNOLD standing by for safety.

2) <u>Measurement of Spider Motion</u> - Over a 30 to 36-hour continuous record of the variations in the acoustic travel time from a bottom mounted pinger to a hydrophone at the apex of Sea Spider was obtained on August 20 and 21. These variations indicate not more than ±10

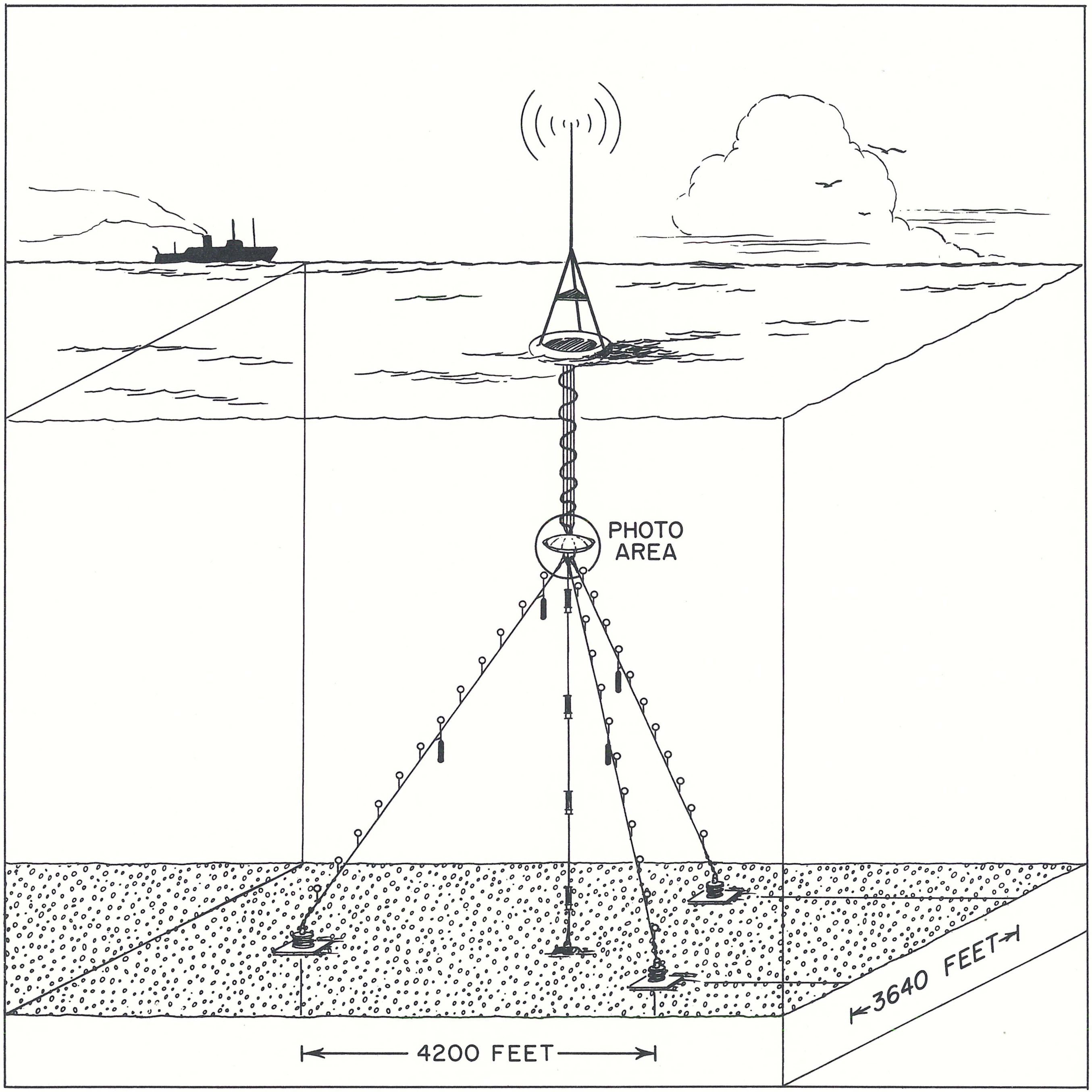


Figure 12. Schematic of Sea Spider.

feet of movement of the Sea Spider apex along a line joining the apex and the bottom mounted pinger. No continuous current measurements were recorded while the Sea Spider motion studies were underway. However, currents were measured for a considerable period just prior to this work. Currents measured by a Richardson current meter at a depth of approximately 20 feet below the subsurface float for the period August 4 to August 18 indicated a maximum speed near 1 knot. During any 24-hour period the average current direction varied less than 30° in azimuth.

3). Current Measurements - Although three of the four current meters were lost during retrieval, the record from the remaining one is remarkably free of high frequency noise (a major problem with other instrument bases) and very encouraging for the potential of Sea Spider as a current measuring base.

4) Thermistor investigation of internal waves - wide discrepancy from calibration of the thermistors after installation eliminated this program.

5) Tension studies to correlate motion recorded for Spider with leg tensions - similar calibration difficulties after installation eliminated this program.

6) Reflection seismology - several Sparker runs recorded on Spider hydrophones indicate that Spider has excellent potential for acoustic studies of the subbottom using deep fixed hydrophones for recording.

7) Bottom reflectivity difference studies - data of high quality recorded. Analysis still in process.

8) A theodolite study to record path of a freely rising sound source to measure current transport - not attempted in absence of complete telemetry capability.

9) Retrieval feasibility - using a mine-cutter type device designed by Frederick Hess, all of Sea Spider but the anchors, some steel wire, and about 50 of the glass floats were completely recovered

in 30 hours, All instruments except the three previously mentioned current meters were recovered successfully.

Subsurface Instrumentation for Sea Spider Buoy (Mr. Dow, Mr. Grant and Mr. Scott)

The Sea Spider assembly consists of a four channel radio-acoustic buoy tethered by a reinforced electrical cable to a subsurface float which forms the top of the hydrostructure described in Mr. Savage's section of this report (see Figure 12). The float is anchored to the bottom by a tripod having 3200-foot legs containing electrical conductors.

Hydrophones and thermistors, mounted on pressure cases containing their respective preamplifiers, are attached to each leg of the tripod near the bottom, and the acoustic and temperature information is piped to the transmitting radio buoy via the conducting legs and tethering cable described above.

A fourth sensor unit is attached to the structure near the sub-surface float to relay surface data in the same way.

These four units (and a spare) along with their respective suspension systems were designed and fabricated at Woods Hole Oceanographic Institution during this period. The Sea Spider structure was planted on July 25-26, 1965 off Charleston, South Carolina and retrieved about a month later.

Although difficulties with the transmitter, swivel, and cabling near the sub-surface float prevented a proper field evaluation of the complete system as a tool for science, engineering information essential to the correction of these problems was gleaned from a detailed examination of the entire underwater structure following its retrieval.

This examination also revealed that, other than two broken steel-cased thermistor leads apparently smashed by the grappling hook during retrieval, all the deep gear and cabling was in good order and that the hydrophone preamplifier and thermistor bridges still followed the original calibration curves indicating excellent long-term stability.

Surface Instrumentation for Sea Spider Buoy System (Mr. Hess)

The Sea Spider buoy plant required the telemetering of four channels of acoustic (hydrophone) information and seven channels of thermistor and load cell data over long ranges (20 miles) by radio. The range requirement necessitated the use of an H. F. channel rather than U. H. F. which is more practical for large volumes (band-widths) of data.

The system block diagram is shown in Figure 13. Hydrophones 2, 3, and 4 are transmitted all the time, and Hydrophone 1 is used when data from thermistors and load cells are not needed. The sampling switch for the data channels was fabricated at Woods Hole and consisted of individual reed switches for each input which were actuated by a motor driven magnet as it passed each switch in turn. This provides low noise switching with no moving or exposed contacts. The sampling rate is one complete set of data each 90 seconds. This slow scanning speed eliminates the need for any expensive de-commutation equipment at the receiving location.

In the Sea Spider experiment signals from the load cells and thermistors were converted by a Voltage Controlled Oscillator (V. C. O.) such that a frequency range of 500 to 4000 C. P. S. was obtained for a 2-volt input signal range. The V. C. O. is a saturable reactor type and its associated D. C. amplifiers give a repeatability of better than ±1% and an overall accuracy of ±2% of the reading. A frequency counter with digital printer was used to retrieve the data from load cells and thermistors.

The radio transmitters were fabricated at Woods Hole and consisted of two, double, independent sideband transmitters. The use of separate, independent sidebands gives immediately a two for one advantage in information carrying capability as each radio frequency can handle two separate types of information simultaneously. Sideband generation is by the mechanical filter method with audio passband of 100 cps to 5. 2 kc at the 3-db points. The sideband generators are heterodyned up to the desired output frequencies (6208 kc and 2398 kc). Linear amplifiers capable of 100 watts peak envelope power are used to assure adequate signal strengths. Both R. F. channels were fed to a common antenna; a 24-foot whip. Reception of signals aboard ship presented no particular problems.

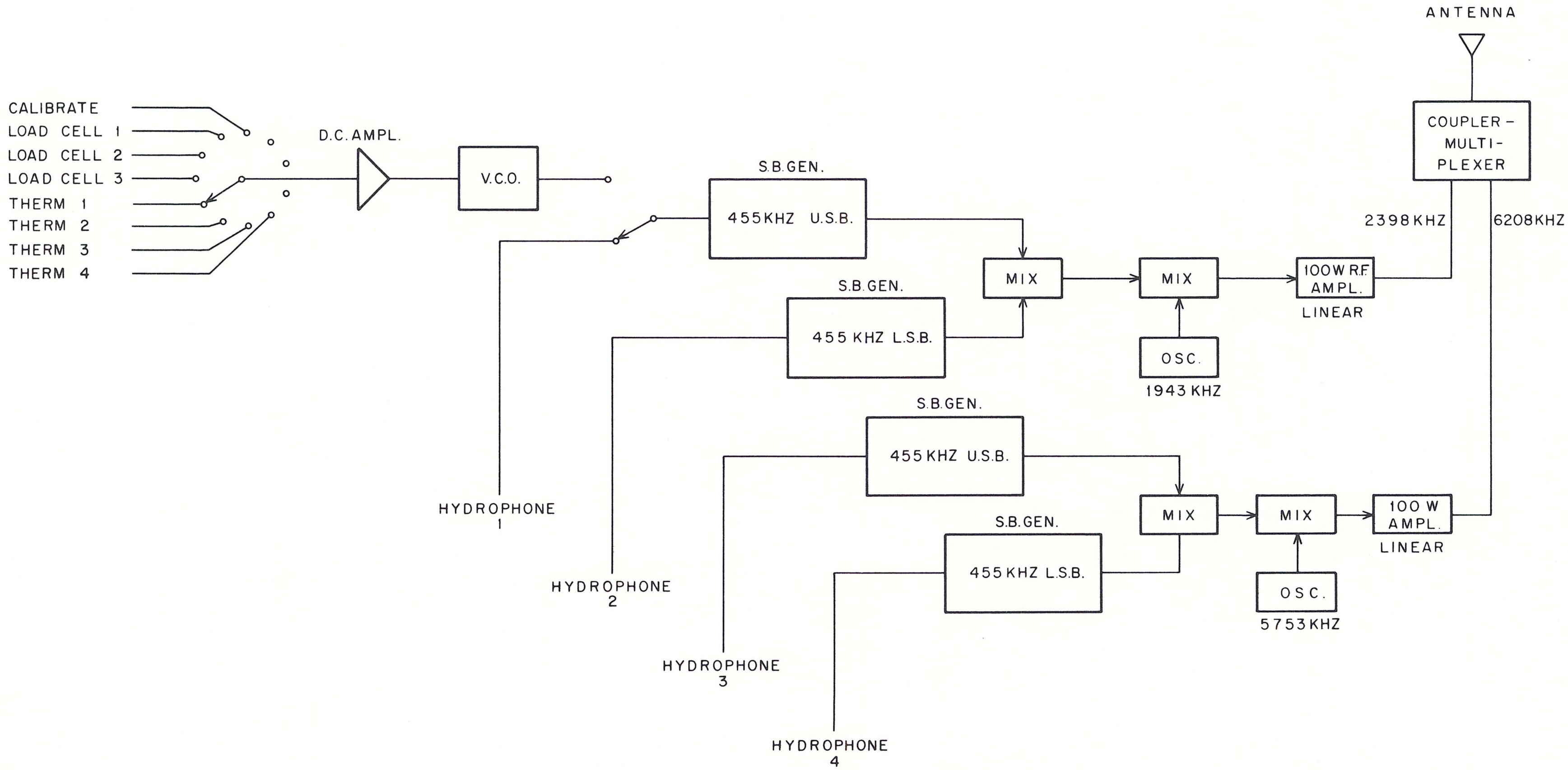


Figure 13. Block Diagram of Sea Spider Telemetry System.

Power for the entire buoy system was provided by a bank of four propane-fired, thermoelectric generators providing 180 watts of continuous power at 28 V. D. C. This generator provides continuous maximum output power for a period of 11 days using three 100-pound propane cylinders. Some difficulties were encountered in keeping the burners lit in high winds but the manufacturer claims this can be taken care of. This method of power generation holds considerable promise for deep sea buoy use, because the ease of changing gas bottles (which float even when full) at sea is so much greater than that involved in changing or recharging batteries.

The first trials of this system at sea did not bring to light any major flaws in the system concept. Considerable difficulties were encountered, however, in preventing R. F. feedback into the low level S. S. B. generation circuits. Considerable R. F. shielding was necessary. Additional difficulties with the common antenna system were encountered due to the wide frequency difference between the two signals generated. More suitable, harmonically related frequencies are available and will be used in further tests.

Shipboard Data Processing System (Dr. Bowin, Mr. Ruppert, Mr. Nichols and Mr. Aldrich)

The shipboard data processing system (IBM 1710 system) was removed from CHAIN for the four-month period of 11 May to 4 September 1965, and placed in inactive storage. It was reinstalled on CHAIN starting September 4, 1965 and has been operational for the remainder of the period covered by this report. Minor improvements have been under consideration and discussed with IBM programmers and engineers. These will probably be implemented during November, 1965.

Our goal is to accomplish at sea as much data analysis and interpretation as possible while investigations are being conducted. The experience we have gained from the operation of a shipboard computer during the last three and a half years has suggested basic requirements for future shipboard computer systems. Since it is not possible to anticipate all the things one might want to do a year hence, versatility and flexibility of designing are extremely important if the ability to take advantage of experience is desired. Multiprogramming capability is essential, including the ability to time-share real-time and off-line programs. The program should be written with a modular construction and preferably in a Fortran-like language with sampling and control instructions. This would allow the user greater ability to modify and expand the program as desired. Core memory should be made as large as practical; the tendency is for best estimates to be too small. Equipment and programs should exist that will prevent failures in peripheral units or external input units from halting or destroying the operation of the other activities of the computer system. It also appears that the use of several similar output devices for the visual recording of the various types of scientific data processed is preferable to one large unit recording everything in a necessarily less flexible format. Last, but not least, reliability should be maximized to the extent that urgency demands, and design and money permit.

In order to investigate the practicality of developing a system meeting the requirements stated above, a request for proposal was submitted to six leading computer manufacturers on February 15, 1965. Subsequently two additional companies requested and were furnished copies of the Request for Proposal. On June 14, 1965 proposals were received from two computer companies, one for a purchase only basis, and one for a rental or purchase only. The proposal from International Business Machines Corporation was the lowest bid. We have asked IBM to modify their proposal in certain aspects, and we are presently awaiting their revised budget proposal.

Using an IBM 1401 computer, programs for the listing of the data and logging disk packs recorded by the shipboard computer system have been completed. For all CHAIN cruises on which the computer system was operating (numbers 41-53), listings have been made and copies distributed to the scientists requiring the data. Computer programs to transfer the information from disk packs to magnetic tape in a Fortran format, and also for the 1401 computer, with appropriate parity and zone checking have also been completed. Most of our data have been transferred, and detailed checking of the results is presently in progress. It is intended to supply the NODC with duplicate tapes of these data as soon as possible.

A listing of computer programs that have been developed and used at Woods Hole under this contract are tabulated in Table 2.

TABLE 2

PURPOSE	COMPUTER	LANGUAGE	SOURCE
Real-time oceanographic data processing and control program	IBM 1710	SPS II D	IBM under contract to WHOI
Loran C position determination from microseconds (card input)	IBM 7090 GE 225	FORTRAN II	"
Time-shared Loran C real time computation	IBM 1710	SPS II D	"
Time-shared VLF position determination from microseconds	IBM 1710	SPS II D	"
Time-shared Long distance calculation and determination of equivalent microseconds	IBM 1710	FORTRAN II D	C&GS with modifications by G. Rupper
Gravity meter calibration program (KAC)	IBM 1710	SPS II D	IBM under contract to WHOI
Velocimeter Data Acquisition program	IBM 1710	SPS II D	"
Gravitymeter potentiometer spring tension converter interface check program	IBM 1710	SPS II D	"
Off-line profile plotting program	IBM 1710	SPS II D	"
(Disk Input) (PLOTDK & PLKMDK)	IBM 1710	SPS II D	"

PURPOSE	COMPUTER	LANGUAGE	SOURCE
(Card Input) (PLOTCD & PLKMCD)	IBM 1710	SPS II D	IBM under contract to WHOI
Time-shared land gravity computation program	IBM 1710	FORTRAN II D	C. Bowin
Land gravity anomaly computation	GE 225	FORTRAN II	C. Bowin
Sea gravity anomaly computation	GE 225	FORTRAN II	C. Bowin
Regional magnetic field computation from spherical harmonic coefficients	IBM 7094	FORTRAN IV	from J. Heirtzler of Lamont adopted from Cain, Hendric Daniels, & Jensen, 1964 - with modifications by Bowin and Ruppert
Gravity computation from 2-dimensional structure models and plotting on HSP	GE 225	FORTRAN II	M. Talwani of Lamont modified by Ruppert and Bowin
Paper tape to magnetic tape transfer to data CHAIN Cruises 28 through 39	IBM 1401	AUTOCODER	C. E. I. R. under contract to WHOI
Segregation of position fix information CHAIN Cruises 28 through 39	IBM 7090	FORTRAN II	IBM under contract to WHOI
Updating of navigation and gravity values CHAIN Cruises 28 through 39	IBM 7090	FORTRAN II	"

PURPOSE	COMPUTER	LANGUAGE	SOURCE
Updating of navigation and gravity value - CHAIN Cruise 41 to present	IBM 1710	FORTRAN II	IBM under contract to WHOI
Sea Bouguer correction card input - card output Matthews tables on tape	GE 225	FORTRAN II	G. Ruppert
Sea Bouguer correction disk input - disk output	IBM 1710	SPS II D	IBM
Subroutine Curve Fit up to order 13 (polynomial)	GE 225	FORTRAN II	F. Keyte
Program to generate new seg fix cards with effective time modified	GE 225	FORTRAN II	G. Ruppert
Program to put Matthews Tables onto tape	GE 225	FORTRAN II	G. Ruppert
Program to put Matthews tables and S-13 table onto Mag tape	GE 225	FORTRAN II	G. Ruppert
Programs to punch gravity data from mag tapes cruises CHAIN 29-39, also mods with/without time shift	IBM 1401	AUTOCODER	Madigan and Ruppert
Plotting subroutines Plot/INPL	IBM 1710	SPS II D	IBM library
Draw	IBM 1710	SPS II D	IBM library
Program to load data from card to disk at specified locations	IBM 1401	AUTOCODER	IBM library

PURPOSE	COMPUTER	LANGUAGE	SOURCE
Program to list mag tape on HSP	IBM 1401	AUTOCODER	IBM library
Console T. W. program to transfer data on disk	IBM 1710	MACHINE	G. Ruppert with assistance from IBM Providence, R. I.
Data Plot - program to generate card input to Electronics Associates flat bed plotter BOUG, FA, WATER DEPTH LAT/LONG	GE 225	FORTRAN II	G. Ruppert
Listing of data disks	IBM 1401	AUTOCODER	G. Ruppert with assistance from IBM Providence, R. I.
Listing of log disks with code selection capability	IBM 1401	AUTOCODER	G. Ruppert wtih assistance from IBM Providence, R. I.
Disk to Magnetic tape in FORTRAN format	IBM 1401	AUTOCODER	"
Disk to Magnetic tape in condensed format	IBM 1401	AUTOCODER	"
Magnetic tape in condensed format back to disk	IBM 1401	AUTOCODER	"
Water depth correction program for data disks	IBM 1710	SPS II D	IBM under contract to WHOI

A method to develop high tensions in a taut-line mooring in deep water (Mr. Knott)

The work during Cruise 53 of CHAIN required a reference buoy, to which a hydrophone was attached, that could be relatively easily set and would hold its position within small tolerances in a depth of more than 2800 fathoms. It was anticipated that the mooring line should have about 2000 lbs. tension at the anchor end and that this could be attained using a Richardson-type buoy which has about 6000 lbs. displacement and an anchor made of 4 railroad wheels weighing about 3100 lbs. in water. Fish-bite problems (WHOI Reference No. 65-22) were to be expected in the region of the Hatteras Abyssal Plain where the buoy was to be placed. This necessitated the use of a 1/4-inch wire mooring line to a depth of greater than 500 fathoms. A 9/16-inch nylon double braided line (made by Samson Cordage) provided the strength, stretch, and non-twisting properties required. Since most plastic lines can tolerate less stretch when wet than when dry before breakage occurs (troublesome above 40% of the breaking strength), a stretch of about 15% was chosen which produced a tension of 20% of the breaking strength (10,000 pounds) of the 9/16-inch nylon. A hydrostatic coupling was used at the anchor so that all but the anchor could be retrieved at the end of operations with the buoy. A 5/8-inch piston in the hydrostatic coupling provided, at depth, 2500 to 2800 lbs. tensile strength which gave 500 to 800 pounds in excess of the required tension of the mooring. The deadweight anchor was prevented from dragging by a 90-pound Danforth attached by a short chain to one side.

Length-of-line and stretch calculations were determined from water depths measured on a Precision Graphic Recorder (PGR) and corrected by Matthews' tables, and from curves supplied by Samson Cordage Works. Calculations of tension in the mooring line, which included the weight of the mooring line and fasteners, were corroborated by observations of the moored buoy's displacement. At least 2000 pounds of tension was attained in the line above the anchor, but the tension did not exceed 2500 to 2800 pounds even during state 6 seas because the hydrostatic link at the anchor did not fail.

As often as practical during the work, the position of the buoy was checked using simultaneously-taken visual bearings and Loran-C determinations of the ship's position. Maximum total migration of the mooring buoy, with another radio-transmitter-buoy of greater drag attached, was within a circle of 0.2 sea mile in diameter. Everything but the hydrophone was successfully retrieved; the hydrophone mount and cable parted during high seas the day before retrieval.

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APPENDIX

Personnel

SENIOR SCIENTISTS

Backus, Richard H.
Hersey, J. B. - Department Chairman
Vine, Allyn C.

ASSOCIATE IN OCEANOGRAPHY

Schevill, William E.

ASSOCIATE SCIENTISTS

Beckerle, John C.
Bowin, Carl O.
Bunce, Elizabeth T.

RESEARCH SPECIALISTS

Dow, Willard, Electronics Engineer
Knott, Sydney T., Hydroacoustics Engr.
Zarudzki, Edward F. K., Seismic Engr.

ASSISTANT SCIENTISTS

Chase, Richard L.

RESEARCH ASSOCIATES

Bergstrom, Stanley W.
Dunkle, William M.
Hess, Frederick R.
Savage, Godfrey H.
Tasko, Edward R.
Watkins, William A.
Wing, Asa S.
Witzell, Warren E.

RESEARCH ASSISTANTS

Aldrich, Thomas C.
Birch, Francis S., Jr.
Boutin, Paul R.
Cain, Henry A.
Carter, Alwyn L.
Collins, Belinda F. (Part-time)
Dakin, Frances M.
Feden, Robert H.
Hays, Helen C.
Johnston, Alexander T.
Jones, Barbara A. (1/2 time)
Karnella, Charles
Laura, Arthur C.
Lynch, Frank L.
Martin, Roger
Mizula, Joseph W.
Nichols, Walter D.
Olmsted, Coert D.
Payne, Richard E.
Perkins, Henry T.
Poole, Stanley E.
Ruppert, Gregory N.
Stillman, Stephen L.
Welby, Kevin M.
Wooding, Frank
Young, Earl M., Jr.

LABORATORY ASSISTANTS

Aldrich, Timothy W.
Buck, Judith
Carlson, Kimberly B.
Church, William J.
Douglass, Jane C.
Easterly, Charles (Part-time)
Fuglister, C. Kurt
Gallagher, Gloria S. (Part-time)
Grant, Carlton, Jr.
Murphy, Christopher
Scott, Carl W., Jr.
Senefelder, Lynne M.
Shores, David L.
Witzell, Grace M.

POSTDOCTORAL FELLOW

Craddock, James E.

DOCTORAL CANDIDATES WORKING ON THEIR DISSERTATION IN THIS DEPARTMENT

Bennett, Lee C. (Bryn Mawr College)
Haedrich, Richard L. (Harvard)
Hoskins, Hartley (University of Chicago)
Nowak, Richard T. (M. I. T.)

COOPERATIVE STUDENTS FROM NORTHEASTERN UNIVERSITY AND ANTIOCH COLLEGE

Clough, John W.	(Northeastern University)
Leary, Richard H.	" "
Jewett, Phillip E.	(Antioch College)
Rosenthal, Roy D.	" "
Turcotte, Richard B.	(Northeastern University)
Winder, Thomas L.	(Antioch College)

ADMINISTRATION

Morehouse, Clayton B.	- Stock Expediter
Stetson, Thomas R.	- Project Coordinator
Sutcliffe, Thomas O.	- Equipment Custodian

SECRETARIES

Broadbent, Alice G.
Mellor, Florence K.
Peterman, Carol I.
Peterson, Jane M.
Rhoads, Sandra S.
Stone, Louise D.

SUMMER

Atwater, Tanya
Bumpus, Kristianne
Correll, Robert
Cox, Donald P.
Cronk, Casper
Delnore, Victor
de Witte, Adrian
Egar, Joseph M.
Erickson, Albert
Garey, John F.
Hall, John K.
Hodgkins, Harry L.
Kurn, Sidney
Mulvey, Lynn
Paris, Jay E.
Rice, Alan R.
Salisbury, Matthew
Sellers, Frank
Tashiro, Kathy J.
Woodside, John

Visitors

Mr. A. J. Barrow	A. C. F. Electronics Division
Mr. J. E. Bissanti	" " "
Mr. D. E. Willig	" " "
Mr. E. M. Zackarus	" " "
Dr. D. E. Weston	Admiralty Research Laboratory - England
Dr. J. Tunstead	Admiralty Underwater Weapons Est. - United Kingdom
Mr. R. J. Kuhn	Aeroflex Laboratory, Inc.
Mr. J. B. Speller	" " "

Mr. H. F. Hamberg	Aircraft Accessories, Inc.
Mr. D. G. Quick	Ampex Corporation
Mr. S. Chilminski	Bolt Accessories, Inc.
Mr. F. P. Diemer	Bunker-Ramo Corp.
Mr. R. O. Dougherty	CEIR
Mr. C. J. Leudens	C. Leudens & Co.
Dr. D. H. Matthews	Cambridge University - England
Mr. P. Nasmyth	Canadian Joint Staff - Washington, D. C.
Mr. R. E. Liebrik	Clevite Corp. - Ordnance Division
Mr. A. Winslow	" " " "
Mr. M. Strasberg	David Taylor Model Basin
Mr. H. S. Burns	Electro Marine Corp.
Mr. R. Andrews	General Electric Co.
Mr. G. Freeman	" " "
Mr. C. A. Conover	" " "
Mr. R. S. Crockett	" " "
Mr. M. F. Lewis	" " "
Mr. P. F. Smith	Geodyne, Inc.
Mr. T. Cantrell	Geosciences, Inc.
Mr. E. A. Robinson	" "
Mr. R. A. Wiggins	" "
Mr. R. White	Hewlett Packard, Inc.
Mr. B. Adams	Hudson Laboratories
Dr. A. Berman	" "

Mr. E. D. Unger	International Business Machines, Inc.
Mr. S. Tilson	International Science and Technology
Mr. C. Vaughn	J. & J. Associates
Dr. G. Siegler	Kiel University - Germany
Prof. H. Evans	M. I. T.
Dr. F. Press	"
Mr. F. Spielhaus	"
Mr. O. Woodworth	Mecca Cable & Service Co.
Dr. H. J. Aufm Kampe	Ministry of Defense - Republic of Germany
Mr. W. P. Hansen	Minnesoto Mining & Mfg. Co.
Mr. D. L. Mainwaring	" " " "
Mr. R. B. Nelson	" " " "
Mr. Michael Getler	Missiles & Rockets Magazines
Mr. J. Gartz	National Geographic Society
Mr. Matthews	" " "
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This progress report contains findings in 1) physical oceanography, 2) marine biology, 3) geology and geophysics, and 4) hydroacoustics. 1) Long-period internal waves are deduced from sound-velocity data between Bermuda and the Antilles. The region of the thermal front (usually found near 30°N) was thought on one occasion to be a generator of internal waves. 2) Midwater fishes were four times more abundant north of the front than south and midwater reverberation levels varied similarly. 3) Evidence obtained southeast of Charleston, S.C. shows that the continental shelf has been building out over the Blake Plateau. The gravity characteristics of many major rifts of the world reveal that as the width of the rift increases, the Bouguer anomalies become increasingly positive. 4) Observations support the hypothesis that diffraction effects are required to explain the sound propagation in convergence zones in the Mediterranean.

A major engineering accomplishment was the installation and use of Sea Spider on the Blake Plateau. Sea Spider is a near motionless platform for scientific measurements in the deep ocean. The development of an automatic digital depth-reading system for use with echo sounders on ships were successfully completed, improvements in seismic profiling techniques were made, and special coherency studies of towed hyrophone array noise have progressed.

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